SCHOOL OF
CIVIL ENGINEERING

INDIANA
DEPARTMENT OF TRANSPORTATION

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-93/6
Final Report

# AN INDOT LESSONS LEARNED CONSTRUCTABILITY PROGRAM AND INTEGRATED MULTIMEDIA SYSTEM

Bob G. McCullouch
Robert Patty

PURDUE UNIVERSITY

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School of Civil Engineering

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16. Abstract

To improve constructability, experienced design and construction engineers often select processes and develop details that require less labor, equipment, or management resources to build. These innovative ideas, enabling circumstances, and their effect on the construction process are not usually recorded in a reusable format. Without such a mechanism, recalling this experience under the appropriate circumstances, or transferring the technology to new management has generally not happened. Further, civil engineers are generally educated to optimize cost by minimizing the material quantity. Through experience gained after graduation, they are expected to pick up options for engineering impact on the labor, equipment, and overhead expense. This school of experience extracts too high a price in trial and error, and the need for redevelopment of lessons learned by others.

Presented is a constructability concept and lesson-learned storage and retrieval platform. This case based technical assistant, has been ergonomically designed to employ natural problem solving heuristic methods used by human experts. Within this platform, the process of locating an appropriate lesson learned matches closely the storage and retrieval mechanisms of the human long term memory. The result is lessons learned which are easy to find.

Once found, the circumstances and construction processes are presented in a multimedia format that can represent all factors affecting construction cost. Human factors research was again applied to the development of this presentation system. It involves the learner, and deepens the understanding, elaborately relating the lesson to prior knowledge, which will further improve the memory recall mechanism created during the search process.

DICEP (Design Integrated Construction Engineering Platform) is presented herein to effectively involve the human design engineer in the application of constructablility at the right time during design.

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## ABSTRACT

To improve constructability, experienced design and construction engineers often select processes and develop details that require less labor, equipment, or management resources to build. These innovative ideas, enabling circumstances, and their effect on the construction process are not usually recorded in a reusable format. Without such a mechanism, recalling this experience under the appropriate circumstances, or transferring the technology to new management has generally not happened. Further, civil engineers are generally educated to optimize cost by minimizing the material quantity. Through experience gained after graduation, they are expected to pick up options for engineering impact on the labor, equipment, and overhead expense. This school of experience extracts too high a price in trial and error, and the need for redevelopment of lessons learned by others.

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DICEP (Design Integrated Construction Engineering Platform) is presented herein to effectively involve the human design engineer in the application of constructability at the right time during design.

# CHAPTER 1
# INTEGRATING CONSTRUCTABILITY INTO ENGINEERING

The architectural, engineering and construction (AEC) industry is the nation's largest, accounting for 8% of the U.S. GNP (USDOCC 1985). Its productivity has been going down at 1%-2% per year since 1960 (Cremeans 1981, Pieper & Allen, 1989). Importantly, this industry provides most of the U.S. public highways, schools, water supply systems, almost all our housing, and accounts for over 50% of the capital investments made by all U.S. production enterprises (Wilson 1987).

## Historical Perspective

A primary factor, contributing to this decline, is the failure on the part of design and construction teams to effectively record, for future use, so called, 'constructability-lessons-learned.' This is not a new problem. For many years experienced construction personnel have provided input into construction projects in order to enhance constructability. Zyhaljo (1987) advised that structural engineers are still not usually trained or educated in construction methods and are therefore unaware of the impact of construction constraints on design. Gee (1989) observed that in order to shift the liability for means, methods and tasks sequences to the contractor, most designs are based on an assumed method and sequence of construction. Fisher (1991,b) claimed further, that due to the fragmentation in the construction industry, structural engineers rarely use explicit constructability knowledge when making decisions about the layout and dimensioning of structural elements. Construction systems tend to be islands of automation in specialized firms. Integration of design and construction is still at the level of face-to-face review meetings and post construction design reviews (O'Connor 1987; Tatum 1987)

## Introduction to Constructability

Constructability has been defined as the integration of construction knowledge and experience during program development, conceptual planning, engineering

design, and construction operations; to achieve project efficiency. Since developing a clear understanding of a project's objectives and priorities is the first responsibility of the owner's team, it necessarily includes construction cost, and its related schedules, quality and safety considerations. Project value engineering analysis can and should include additional consideration for aesthetics, reliability, leasability, public image, operability and maintainability, etc. (Tatum, Vanegas & Williams 1985).

Construction experience, the subject of this research, is knowledge based on methods to perform construction field operations, gathered primarily from the results of prior projects. This knowledge provides technical, operational, contractual, or administrative guidance for subsequent projects. (Reuss & Tatum 1993) The primary objective of constructability is the enhancement of project performance. This may be accomplished by using construction knowledge or lessons learned especially during the planning, conceptual and schematic design phases. Doing this at the early stages will significantly reduce construction labor and equipment cost, decrease the amount of change orders, help prevent cost overruns, lessen scope growth, and most likely minimize claims, time extensions, and litigation.

The advantages of constructability programs are well documented. In the mid 1970's Proctor and Gamble developed a manual on constructability, based on 13 in-house case studies documenting the benefits of a concerted effort (Constructability-It Works 1977). Ardery (1991) found they will pay off 10-20 times the cost of the program. The Construction Industry Institute (CII) reported that specific projects have realized a 6-23% savings and project schedule savings of up to fourteen months, by the addition of a constructability program (Constructability: Primer 1987). Fisher (1991) determined that through such programs engineers can be trained more quickly, and better decision support data and knowledge will be available. According to Jaselskis (1988), the probability of successful project schedule performance increases from 2% to 33% with a constructability program. Indeed, implementation of a constructability program seems to have a significant impact on achieving overall project success as well as better schedule performance - especially on fixed-price contracts (Jaselskis & Ashley 1991)(Ardery 1991).

## Problem Statement

Prior research has concentrated on establishing the need for, as well as management aspects of establishing a constructability program. The Construction Industry Institute (CII) recently recognized the potential for automated information technologies in this field by the addition of the following statement to their key concepts list.

> 8. "Advanced technologies are applied throughout the project. This concept addresses achieving enhanced constructability by exploiting the capabilities and benefits of advanced information technologies. The use of advanced technologies has the potential to revolutionize the methods used by the construction industry. Some of the information technologies being applied to projects include the use of three-dimensional computer modeling, relational database systems, expert systems, computer simulation, electronic data interchange, bar coding, and field notebook computers. The emerging technologies provide opportunities to better apply construction knowledge and experience through an improved interface between project engineering, construction, and maintenance personnel." (Russell & Radtke 1992)

Other researchers have focused on what is wrong with specifications or design drawings, on conflict resolution; or on the use of a new technology, such as hypertext, or expert systems; or even on replacing the human. But no one has concentrated their efforts on the user interface, what he really needs, and how to expand the value of manual systems with the full range of artificial intelligence combined with the educational power of multimedia. Specifically, no hypermedia constructability systems exist.

Further, the search for constructability-lessons-learned has been concentrated in the industrial (manufacturing, process systems, and power plant) construction area. Some attention has been given to identifying concepts for building construction, and much of this work is relevant and will serve as a strong base for this research. But outside of the work done by O'Connor and Blaschke, very little effort has been given to define and delineate shortcomings in current transportation design process from a viewpoint of constructability.

A design review is the usual mode of employing constructability knowledge. This process, whether it is done manually or in some automated fashion, suffers from the need to evaluate the reviewed design against a vast quantity of alternatives. If attempted manually, the volume of information severely overloads the human working memory capacity. This situation causes even the most qualified experts to use heuristics in an effort to categorize and simplify the problem.

Automatic evaluation requires intelligent representation of each design to be evaluated as well as all standards for comparison in some mutually comparable format. This is formidable and has not been successfully demonstrated except for small applications. Fully automated 3-D design and constructability analysis is not economically practical at this time. Indeed we should be seeking ways to more effectively involve and support the human design engineer, rather than replace him. Further, the review process is inherently wasteful in that it requires a design to be produced and detailed in some traditional or automated form before it can be evaluated.

Current user friendly multimedia systems facilitate representation of the effect of design decisions on labor and equipment costs. These systems can enable designers to complete their understanding of the cost equation which has to this point been largely based on optimization by material quantity reduction alone.

## Research Objectives

This research ties into past efforts and carries the constructability idea further by focusing on the interactive application of constructability knowledge during the design phase of transportation structures. The factors identified in prior research and the classification systems served as a starting point for the development of this graphical user interface for the selection of applicable constructability factors and for the acquisition of construction knowledge as well as its representation using hypermedia.

Specifically, the following were performed:

1. Review existing literature to identify constructability program recommendations

and experience. Define and delineate the strengths and weaknesses of current transportation design process and recommend systems for constructability experience collection, storage and retrieval, in this domain.

2. Using prior work as the starting point, focus on the transportation design engineer and on principles of ergonomic human-computer interface development to determine how to expand the value of state-of-the-art manual or hypertext systems by utilizing graphical user interfaces, multimedia, and artificial intelligence.

- A. Identify the types of information needed
- B. Identify advantages and disadvantages of alternate means to capture this information
  1. During the ongoing construction phase of a project
  2. From secondary sources
  3. From experts reviewing standard details and specifications
- C. Develop data collection frameworks for
  1. Interviews
  2. Conflict resolution which must be done prior to representation
  3. How constructability concepts are to be captured in electronic format
     - a. Text
     - b. Still graphics
     - c. Sound
     - d. Video clips
- D. Identify, acquire, compile and classify sufficient design relevant constructability lessons learned in the selected hypermedia system format to enable a proof of concept.

3. Create an intelligent bridge or graphical user interface between stored lessons learned and the engineer in the design process. This will be accomplished through rapid prototyping. It will provide a structured, nonlinear guide through the process which is carefully designed to effectively train and support the human design engineer

and not overload the short term memory. Consideration will be given to a more structured communication process for specialized project participants.

4. Evaluate and quantify the improvement value to justify full scale development.

# CHAPTER 2
# STATE OF THE ART

When construction process problems are addressed in a timely and systematic way, highly trained engineers and practitioners often can and do develop innovative solutions which save the project significant time and money. Unfortunately, such solutions are often highly job specific, requiring many peculiar conditions to exist in order to justify their deployment. As a result, it is widely considered of little value to record them for possible future use.

The experience becomes a sort of expertise developed by the involved party which does not get disseminated much beyond the original group. Even for those involved, the experience may or may not be recalled at appropriate times in the future, depending on how analogous the future problems are to the conditions under which the understanding was stored in the long term memory of such developing experts.

Compounding the problem is that construction projects are usually long term, lasting 6, 12 or even 36 months. Those most qualified to make constructability process input are normally engineers assigned to the task of construction management. Due to the relatively long duration of projects, an individual may only be directly involved in 20 to 50 projects during an entire career. What is lacking, is a method to effectively record and retrieve constructability-lessons-learned.

## Plan and Specification Review

Most constructability programs currently consist of reviews. The review is used to identify omissions, ambiguities, and inadequacies of the design documents, and it produces marked up drawings and specifications. The reviews check for accuracy, completeness, cost effectiveness, and compatibility with project constraints, and suggest lower costs alternatives. Although useful, this necessitates design rework, and leads to adversarial relationships between design and review personnel. Indeed, one of the biggest obstacles to good constructability occurs when personnel are excluded from the design phase except for a review of completed or partially

completed designs.

Under these circumstances, designers often become defensive because they risk public acknowledgement of defective design documents. Reviewers are reluctant to comment in order to avoid appearing overly critical. The separation of design and construction personnel along with formal reviews can deteriorate the environment to an adversarial relationship. (Constructability: Primer 1987) Design rework is less costly than construction rework, but, this approach occurs too late during design to influence the major construction methods. However, even the most proactive constructability programs have construction personnel reviewing documents prepared by design. But proactive reviews are not confined to checklists nor are they timed at a set percent of design completion. Proactive constructability contributions are made by frequent informal meetings (Russell & Radtke 1992).

Blaschke (1989) identified specifications as a key element for review in any constructability program. It is the interpretation and administration of the specification that becomes the critical issue. And this is predominantly dependent on the judgement of the engineer and the inspector. The ability of an engineer and inspector to use the specifications as a guide where appropriate as opposed to an absolute requirement is the result of training, experience, knowledge of current practice and good judgement. The goal is practical interpretation and substantial compliance with the specifications to achieve the desired product.

Interviews are the most widely used knowledge acquisition technique for this type of knowledge because they allow for direct interaction between the expert and the knowledge engineer. Fisher used peer recommendation to select experts. Sample cases usually served as a starting point to help trigger experts' responses. Designers provided him with the questions they would ask a construction expert if they had to design a structure for construction using a specific method (Fisher 1991). After extensive elicitation in the transportation domain, O'Connor et.al (1989) also concluded that personal interviewing was the most effective data collection technique for dealing with the complex, multi-organizational, and often controversial issues of constructability. In fact, it is suggested that each of the desirable attributes be

thoroughly addressed in an interview setting.

"By prompting respondents with general problem types, such interviews may serve as an effective mechanism for determining the complexities of issues or for exposing problems that might otherwise go unnoticed. Following the identification of problem areas and the collection of ideas, comments are screened and lengthy debates may be necessary. New or revised specifications should be reviewed for acceptability against various criteria (such as durability and life-cycle costs) and checked for consistency with other specifications." (O'Connor et.al 1989)

### Types of Information to Collect

Previous research has identified the types of information regarding construction experience on projects that would assist in design, procurement, and construction on later projects. Most of the paper databases that were identified by Russell and Radtke's (1992) research contained a collection of post-project reports and meeting minutes. They recommended a focus on the practicality of the design, cost effectiveness, functional reliability of specific details, compatibility with project constraints and level of document completeness. Their data suggests that attention to construction-sensitive scheduling has the greatest impact. Of groups from 16 projects employing 3-D CAD, five selected it as the most significant concept used during design, to avoid physical interferences. Other highly rated suggestions included developing a project execution plan which includes constructability, and making a special effort to standardize design elements. Major construction methods have to be identified early, since they may determine how the project must be designed.

Constructability lessons learned, and their category descriptions, which are suggested by other authors, and which are applicable to the transportation domain; are included in appendix A. A review of these concepts will reveal several weaknesses:

1. It is often unclear how to translate a listed guideline into specificconstraints for a construction method to be considered.

2. The value of employing the guideline is usually not quantified.

3. While reasons may be given in the higher quality studies, qualifications and exceptions are not noted.

To enable the transition from a review mode to a design which includes constructability principles in the first place, requires a correct understanding of appropriate principles and their related importance in the working memory of the design engineer at the key point when the correct decision needs to be made. Multimedia is a technology which can enable both the recall and synthesis to occur with a broader and deeper scope than text or printed material alone.

**Automated Constructability System Prototypes**

Many existing constructability system prototypes can capture knowledge related to construction experience and make it available in compliance with a number of sort commands, but cannot reason about the presence of appropriate conditions for its application. Fisher (1991) demonstrated that constructability knowledge can be collected, and represented in an expert system. A reinforced concrete structure to be evaluated is modeled in CAD and linked to his expert system. The system checks constructability requirements for various construction methods and generates messages with proposed changes. It is then left to the designer to accept a change or to overrule it based on other criteria. Additional knowledge acquisition would be required to collect the knowledge needed to think through complex interdependencies and to provide the cost data required for optimization. (Fisher 1991)

Lee and Clover created a hypertext system entitled, 'Constructability Improvement of Highway Projects in Washington,' (Lee & Clover 1991). While useful for identifying many topics of interest, its source is confined to an analysis of change orders. It can be characterized as organized statements of complex issues, and lacks depth, conditions, or implementation knowledge. Consideration of conflicting goals, and investigation to resolve them is also lacking.

O'Connor et.al (1989) presented a hierarchically modeling method which they adapted from value engineering techniques for representing constructability objectives. Once major problems are identified, high-order objectives (concepts or strategies) are followed by lower-order objectives (tactics or ideas). Diagrams may be developed in as much detail as desired, with the end-nodes often serving as a catalyst for innovative problem-solving. The criticality of high-order objectives and the controllability of corresponding lower-order objectives are assessed to determine needs for further action. Criticality relates to potential or frequency of impact or benefit. Controllability relates to implementability or ease of execution or deployment. Critical yet uncontrollable objectives are targeted for further analysis.(O'Connor et.al 1989)

Development on this system, which is knowledge based and PC- driven, project stopped in 1990. It didn't answer field questions and wasn't field friendly. This domain exhibits a strong need for both expert system reasoning and multimedia storage and presentation technologies, as well as the need to address conflicting goals and their resolution prior to storage. A constructability system appropriate for use in a state department of transportation such as INDOT, does not currently exist. A system to address these needs should be developed in a manner that every object is usable and useful as soon as possible, as opposed to the requirement of a completed representation of available knowledge in the domain. The technology exists to collect, store, and present constructability knowledge in an intelligent multimedia format.

**Hypermedia**

Most computer users are used to dealing with a text based world, it is not "natural" in the sense that text not only limits the scope of information we can grasp but text can make it more difficult for us to understand some topics because it requires the brain to continuously code and decode information. It would be more effective to communicate using text and other media that can draw upon and be encoded in the long-term memory with real-life experiences. Multimedia can help by bringing together

sights, sounds, text and images in a single communication medium. The second feature of multimedia is non-linear navigation, often termed "hypermedia."

Hypermedia systems allow huge collections of information in a variety of media, to be stored in extremely compact forms, as well as accessed quickly and easily. Thus, comprehensive and diverse materials can be assembled and delivered to learners. A good program demands learner interaction, and it constantly accesses the individual learner's progress (Oblinger 1992).

It is well documented that we have a sort-term retention rate of about 20% of what we hear, 40 percent of what we see and hear and 75 percent of what we see, hear and do. When using multimedia, students complete courses in one-third of the time of traditional instruction, while reaching up to 50 percent higher competency levels. In most cases the overall cost of instruction is lower, as well. (Oblinger 1992) Multimedia mirrors the way in which the human mind thinks, learns and remembers by moving easily from words to images to sound, stopping along the way for interpretation, analysis and in-depth exploration. "It offers a 10 to 20% improvement in performance over conventional teaching methods and a one-third reduction in time on task. That can reduce the amount of time that a student spends learning by one-third." (Oblinger 1992)

Rather than attempting to replace the human with automation systems such as expert systems existing technologies exist that can be utilized to enhance and improve a designer's capacities. There exists a vast quantity of constructability experience that needs to be collected, quantified, and its conflicts resolved; and then represented in a rich and easily retrievable format. Therefore, the need exists for a system to be developed which can blend human capabilities, applicable constructability knowledge, and the technologies that can represent such knowledge to enable their identification and use at the point of design. The next section describes the process used in defining the framework for the prototype development.

# CHAPTER 3

# PRINCIPLES OF HYPERMEDIA CONTENT DEVELOPMENT

## Interviews at INDOT

To identify the goals and objectives for the content of this system, unstructured interviews were conducted with INDOT Division of Design and Operations Support personnel. The objective was to obtain general background knowledge on the following:

1. A general description of the design process used at INDOT,
    a. Structure of the project flow through the system
    b. Available design resources for the implementation of design and constructability principles.
    c. Department organization
2. Training programs for new engineers
3. General level of experience of design engineers
4. Feedback mechanisms for field experience
5. Mechanisms to record and disseminate constructability data from field experience.
6. General feelings about what should be included in an intelligent or knowledge based multimedia system to make the greatest impact on the inclusion of constructability principles during design. Appendix A & B contains names of INDOT personnel interviewed and transripts of the interview.

## Interview Results

INDOT utilizes many resources in the design of facilities. The main ones, which could be included within, or hyperlinked to a constructability system, include:

1. Indiana Department of Highways Standard Specification, 1988
2. Structural design programs
3. Book of standard details for bridge and highway design.
4. HEC 2 Hydraulic design system

5. FHWA Analysis system for traffic
6. BAMS Manual for contract management
7. Video log of the entire state transportation system
8. GDS CAD graphics design and detailing system.
9. Interoffice notes/detail for explaining design or specification changes.

Additional resources currently being developed which should also be represented within or referenced to the constructability program include:

1. A new seven volume design manual that is being developed by an outside consultant.
2. A CAD based computer program for design detailing of three-span, cast-in-place, flat bridges.

Constructability Items Suggested

Lessons learned suggested by INDOT personnel as appropriate and useful for constructability include the following:

1. Is there sufficient room for equipment to operate within jobsite limits?
2. How can the clear-zones for safety be effectively included?
3. There is not a list of what should go into preliminary plans. Identify what should be included and why.
4. List milestones and requirements for each design function.
5. System to explain why we do what we do during design, with an example plan and a checklist for each page; what sheets should be there and which shouldn't.
6. Still and video graphics showing the way things are actually constructed. For example, videos of regular operations, like pile driving, forming, placing embeds, casting pier caps and pouring bridge decks.
7. A library of standard details with advantages, disadvantages, what to use and what to avoid; with specific details. Identify what makes some details great and others a nightmare. Circumstances for use and specific

assumptions used for details need to be delineated.

8. Help in selecting splice locations on steel beams; include criteria for beam flange width changes, and stiffener-web design tradeoffs.
9. Decision support or expert system for pile selection on bridges.
10. An intelligent front end for standard design programs to weed out what doesn't fit the program and identify why a particular job doesn't fit and what to do about it. (For example, superelevations)
11. Current procedures include no life cycle, or maintenance cost analysis. The department has lots of examples and pictures, but no numbers to use for a quantitative analysis. There is a need to reduce pictures and examples of maintenance problems and life cycle information to quantifiable numbers for use in alternative, value engineering analysis. The department has a historical storage of 10-40 years of repairs, including type and cost.
12. A system to help reduce errors in the application of INDOT unit cost data to the investigation of alternatives
13. A system to evaluate changes in type, spacing, and # of girders to use for bridge design -- For example the 'T' style precast girder, proposed last year, saved $.75 Million on one job.
14. A system to interface with design, providing good and bad options, for comparison, but not to do design
15. A system to gather and infuse the department with ideas from out of state
16. The best system would be compatible to and from CAD.
17. Provide clear-zone definitions
18. Delineate guardrail/bridge termination options
19. Assist in the design and evaluation of traffic control/maintenance
20. To avoid problems with sequencing of construction & matching elevations.
21. Track design memos, revisions and revision-of-revisions
22. To minimize utility problems, including drainage & unmovable utilities,

which the design requires moving.

**Consultant Design Management**

About 20% of INDOT's bridge design work is done in-house, the rest (80%) is designed by consultants. To manage bridge design work done by consultants, an INDOT engineer is typically assigned the coordination of 20-30 consulting projects with ongoing work in design and 10 more that are under construction. Primary functions for an INDOT engineer managing outside consultant design include:

1. Review of the alignment set by consultant
2. Review of the accommodation for construction phasing
3. How will the design avoid closing the road?
4. If a run-around is to be provided, is it large enough?
5. Has the district been consulted for how traffic is to be maintained?
6. Perform a cost comparison based on INDOT's unit cost data.

Ten percent of road design is currently accomplished with in-house engineering and 90% by consultants. To assure the inclusion/ resolution of constructability issues, designers apply their own experience and expertise, and are encouraged to call contractors, field engineers and other consultants. Research conducted by others nationally and internationally, and this research specific to INDOT's level of constructability, indicate that more effort is needed. DICEP is a new tool which can significantly enhance the effectiveness of this increased effort.

**Contractor/Consultant Interviews**

Interviewing Procedures

The interviews at INDOT provided an understanding of the current functions and operating procedures of Program Development, Division of Design, Operations Support, and Technical Services, as well as the motivations and needs for this project. Following the INDOT interviews, contractor owners, general managers, estimators, project managers, consultants and superintendents who were considered experts in

their domain by the INDOT experts, were interviewed. (See Appendix B for full transcripts of five video taped interviews.) The following principles were developed (Heart 1986)(Firlej & Hellens 1991) and employed during these interviews:

1. The purpose of the study was explained, and terminology defined to assure appropriate knowledge could be obtained.

2. With permission of the interviewee, the session was video taped to enable uninterrupted, rapid knowledge elicitation without the necessity or inaccuracies of manual recording. This enabled the interviewer to concentrate on the depth and scope of the interview rather then its recording.

3. An unstructured approach was found to be most comfortable in the early stages. A diligent effort was made to identify new concepts, external identification logic and internal qualifications and exceptions. The expert was probed for reasons, both quantifiable and non-quantifiable benefits, and examples which could be represented in any of the broad range of multimedia formats for instructional purposes.

4. The interviews lasted from two to four hours each, and often involved multiple experts.

5. The interviewer attempted to elicit as complete a description of the concept as the expert was able or willing to give, including: interrelationships, assumptions, constraints, examples of how concepts were formed, why the expert moved from one belief to another, and quantifiable evidence for the concept.

6. Examples of specific, typical or unusual cases were requested in the interview. This often required probing, prompting and questioning to obtain examples

7. As each case was built, the various media forms were considered to enhance the definition.

## Results of Contractor Interviews

Contractor supervisory and management personnel were willing to share their constructability concepts and lessons learned due to their perception that through such input, their construction costs, or at least unknowns at bid time, would be reduced. (see Appendix C) Later review of these early concepts with district engineers and

department heads at INDOT revealed competing concepts, additional costs and a far greater complexity than was apparent when the knowledge was elicited from contractors.

Seldom was a concept so simplistic that it could simply be solicited from an expert in one organization, and represented in the knowledge base without consideration by and approval of other impacted parties. Nearly all these concepts will cost some party more than they are currently paying. The motivation lies in the synergistic and coordinated whole costing less then the current.

**Development of INDOT Constructability-Lessons-Learned**

The result is a potpourri of constructability-lessons-learned, (see Appendix C) some of which are nearly ready for representation in the logic search base, and will save a few thousand dollars on projects where they are used. (Eg. Pile cap bottom forming, Appendix C)

These interviews highlight the need and techniques used for conflict resolution. Appendix C presents several concepts, which if implemented in Indiana, would appropriately be included in a constructability system for the National Transportation Board.

**Organization of Lessons Learned**

As previous researchers have noted, lessons learned should be sorted by type of information likely to be needed as defined by the job of the current user, phase of the project, and current task. The system should enable a user to quickly locate an appropriate lesson learned and evaluate/ quantify the improvement/ value of suggested improvements. Principles and examples must be organized for use at an appropriate sequence of design and construction. It is not possible to do all things in parallel, some tasks are and must be serial (sequential). For example, not all information can be concentrated at the front (conceptual stage). However, what is useful for one engineer working at the conceptual stage, may also be quite useful during design and later stages. It is important, therefore, that the organization and retrieval mechanism be easily customized to meet a particular engineer's needs.

# CHAPTER 4
# PROTOTYPE DEVELOPMENT AND PRESENTATION

This chapter documents the effort for the prototype development. It describes the hardware and software used, some of the difficulties encountered, and an explanation of how the prototype works. Because of the multimedia content a demo disk is not available for distribution. The next phase project will create a CD-ROM disk version which can be distributed.

## Prototype Development

Based on the needs for multimedia development in the prototype system, the software and hardware listed below were procurred.

### Development Software

1. IBM DOS 5.02
2. Windows 3.1
3. WordPerfect 5.2 - for Windows to generate and organize concepts
4. Folio Views 1.0 for Windows for:
   a. Text compression,
   b. Presentation interface
   c. Boolean search
5. ICON Author
   a. Combine and annotate Video and Audio clips
   b. Size and operate playback windows
6. PowerPoint - to create and/or annotate still graphics
7. Calera WordScan Plus - for optical character recognition
8. Visual Basic - to program the graphic user interface system
9. D-Vision Basic - Video Capture and Editing Software
10. Norton Utilities V6 - to avoid fragmented disk conditions
11. PhotoFinish - to control the creation of scanned image bitmaps and to highlight and annotate those images

### Development Hardware

A. PS/ValuePoint Multimedia System 6384 M52
   1. IBM 486DX 33mz
   2. 8 MB Ram

3. 350 MB IDE Hard Drive for program storage
4. Maxtor MXT 1240S 1.2 GB 3.5" Hard Drive for data storage
5. Adaptec AHA-1540C SCSI Port Card with drivers to support the Maxtor SCSI Drive
5. 250 MB Colorado Backup Tape Drive for backup and long term storage
6. 17 inch VGA Monitor

B. SoundBlaster 16 Sound Card with speakers and recording microphone
C. IBM-Intel Action Media II Card for Video Decompression & Playback
    1. With Video Capture option board for analog to digital conversion and compression
D. 1600 X 1600 DPI Full Color Scanner HP Scanjet IIc

Visual Basic was used to develop the Windows environment. This is a familar environment with most computer users and this software provides the development tools. The windows and the navigation process was developed with this software. Folio Views is the software that contains the Constructability Lessons in text form. The Folio software is used to store, index, and retreive the lessons. From a lesson, links into other media forms can be created to improve the understanding and retainability of the lesson.

**Avoiding pitfalls in multimedia system development**

Multimedia development systems are often assembled from a variety of component manufactures. Powerful components such as sound and video cards, SCSI adaptor ports, and video capture software consume large blocks of available resources. If the entire system is not assembled and tested before the sale, many conflicts are likely to occur when the user assembles the system.

Memory BIOS (basic input output system) block addressing, I/O (Input/Output) port addresses, IRQ Interrupts, and DMA addresses are often preset to default values by the OEM (original equipment manufacturer). The base PC (personal computer) may, or may not have these default addresses or memory spaces free or available for use. Additionally, many of the adaptor card or program default values may be the same, and thus create overlaps and conflicts.

Unfortunately software, or expert systems have not been developed to assist the user in eliminating these system errors. The user is often left with little or no intelligence to attempt to resolve the conflicts, other than the fact that the system doesn't work. Hardware and software documentation is often woefully inadequate to resolve the conflict, and the user must resort to technical phone support. With so little evidence to resolve the problem, or identify the guilty party, an advantage can be created if the package can be purchased from a single integrated supplier that has the technical understanding and commitment to resolve setup problems.

Because multimedia development systems consume the vast majority of PC system resources, the following procedure is useful to avoid the random change-the-setting-and-test routine typically suggested.

1. Obtain the general system board information from the PC supplier to include interrupts, ROM (read only memory) address map, I/O address map and DMA numbers used by the system and those available for user installed hardware.

2. Draft a system hardware address chart similar to table 4.1, listing all adaptor hardware defaults and options (usually selected by changing dip switch, jumpers, and/or initialization software settings), for memory BIOS, I/O ports, IRQ interrupts and DMA numbers. This information is available in setup documentation or from technicians at the adaptor OEM.

3. Draft a memory map of the free space and adjacent areas of the upper memory block in hexadecimal, similar to table 4.2. For efficient use of the DOS limited upper memory area by terminate-and-stay-resident drivers, selected BIOS frames should be as sequential as possible, leaving unused space in a single block, at the top or bottom of the free space.

With all the applicable information available, the user can intelligently select addresses and ports which do not conflict. Unresolvable conflicts, may require alternative hardware, software, or separation of functions by the creation of multiple ataxic.bat and config.sys files. Swapping the system files requires a reboot between functions, so should be selected only as a last resort.

## Table 4.1 System Hardware Addresses

| Adaptor Hardware | Memory BIOS, h Start | End | I/O Port Address, h | IRQ Interrupts | DMA |
|---|---|---|---|---|---|
| VRAM D-Vision | C4000 | CSFFF | | 11,2 Capture | |
| ActionMedia 11 w/Capture | C6000 | C7FFF | 2E4 | 10 Video | None |
| Scanjet IIc Color Scanner | C8000 | CBFFF | None Used | 0 | None |
| Adaptec Card | CC000 | CFFFF | 330-334 | 15 | 7 |
| Sound Blaster 16 | Unknown | | 220-233 Base<br>300-301 MIDI<br>200-207 Gameport<br>388-38B Music Syn. | 5 | 5 @16 Bit<br>1 @ 8 Bit |
| IBM Mouse<br>Serial Mouse | | | | 2<br>4 | |

## Current Memory Map

IBM PS/ValuePoint System 6384 M52

| Memory BIOS Area | Frame, h | | Frame, d | | Size, d |
|---|---|---|---|---|---|
| Video Graphics Buffer | A0000 | AFFFF | 655360 | 720895 | 65535 |
| Monochrome Video Buffer* | B0000 | B7FFF | 720896 | 753663 | 32767 |
| *use with dos not windows | | | | | |
| Video Text Buffer | B8000 | BFFFF | 753664 | 786431 | 32767 |
| Start Free Space | C0000 | C3FFF | 786432 | | |
| Insert Include Emm386 i= | C0000 | C5FFF | 786432 | 802815 | 16383 |

| | | | | | |
|---|---|---|---|---|---|
| VRAM D-Vision | C4000 | C7FFF | 802816 | 811007 | 8191 |
| ActionMedia 11 w/Capture | C6000 | CBFFF | 811008 | 819199 | 8191 |
| Scanjet IIc Color Scanner | C8000 | CFFFF | 819200 | 835583 | 16383 |
| Adaptec Card | CC000 | DFFFF | 835584 | 851967 | 16383 |
| Insert Include Emm386 i= | D0000 | DFFFF | 851968 | 917503 | 65535 |
| End Free Space | | | | 917503 | 131071 |
| Video Rom BIOS | E0000 | E7FFF | 917504 | 950271 | 32767 |
| ROM BIOS (Used by System) | E8000 | E9FFF | 950272 | 958463 | 8191 |
| ROM BIOS (Post area) | EA000 | F1FFF | 958464 | 991231 | 32767 |
| | F2000 | F2FFE | 991232 | 995326 | 4094 |
| ROM BIOS (Used by system) | F2FFF | FFFFF | 995327 | 1048575 | 53248 |
| | | | | | |
| D-Vision EMM386.exe Statement | | | | | |
| Emm386 i= | B0000 | B7FFF | 720896 | 753663 | 32767 |
| Emm386 i= | C0000 | C3FFF | 786432 | 802815 | 16383 |
| Emm386 x= | C4000 | CFFFF | 802816 | 851967 | 49151 |
| Emm386 i= | D0000 | DFFFF | 851968 | 917503 | 65535 |
| Frame= | D0000 | | | | |
| | | | | | |
| Windows EMM386.exe Statement | | | | | |
| Emm386 i= | C0000 | C5FFF | 786432 | 811007 | 24575 |
| Emm386 x= | C6000 | CFFFF | 811008 | 851967 | 40959 |
| Emm386 i= | D0000 | DFFFF | 851968 | 917503 | 65535 |

### Operating System and Procurement Recommendations

The system requirements for a multimedia development station are extensive, and the severe memory limitations that DOS imposes may limit capabilities, or create an unfriendly environment for system use. Windows NT or OS-2, which are not so limited will, of necessity, be the operating systems of choice for this type of work in the future. The next phase project approved by JHRP, " INDOT Constructability System Working Module," will shift the operating systen to OS/2 from the current Windows/DOS.

One important test is the video capture and playback process. A video tape with a sample of the material to be captured, should be taken to a fully functional system for a demonstration. A three to 10 minute segment should be captured, and the editing functions observed. Appropriate compression options (inter, and intraframe quantization, number of frames between base frames, and number of frames per second), should be selected and the edited clip compressed. The playback software should then be opened, and the result viewed to assure the quality and size meet the need, and that the playback is smooth and uninterrupted.

### Prototype Description

This section presents the DICEP system developed in this project. Typical window screens are presented roughly as a user would learn, or operate the system. The screens are followed by a description of the ergonomic principles utilized, and additional implications for practice and research.

## Initialization and Database Selection

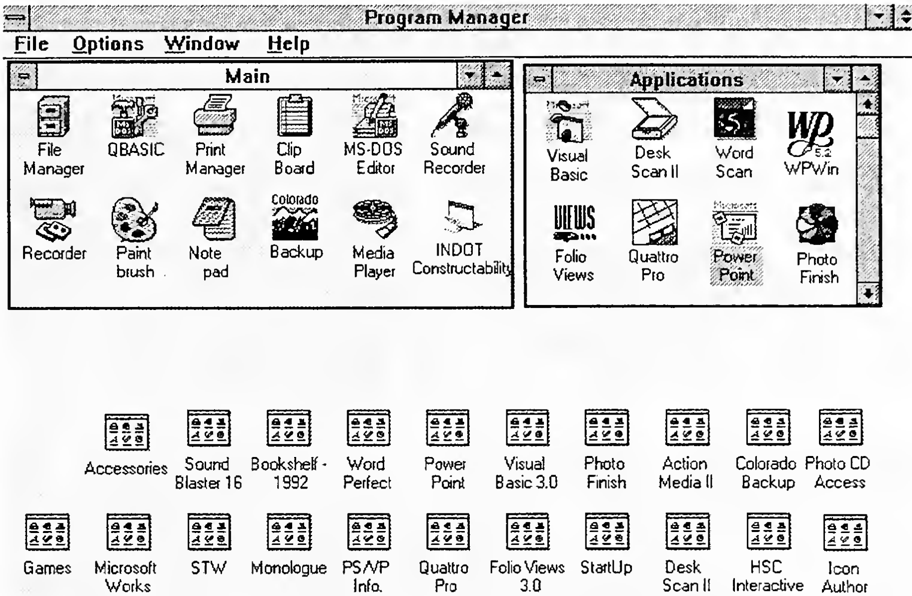


Figure 4.1 Windows program manager

The system starts with the Windows environment program manager screen. From this environment, the user has access to a graphical user interface, and the potential to operate DICEP as a help system in the background to enhance the constructability of other design systems. The standard Windows clipboard provides for simple and convenient transfer of text or graphics in or out of the database, to any other Windows-compatible program. Extensive object linking and embedding capabilities are also available.

From this opening Windows screen, an icon was developed for initiating the DICEP system. One objective for this system was to develop it in a format that most users are familiar with. Therefore, a Windows format was chosen that uses icons as navigation aids. Double clicking with the mouse on this icon, gains access to the

opening screen shown in figure 4.2.

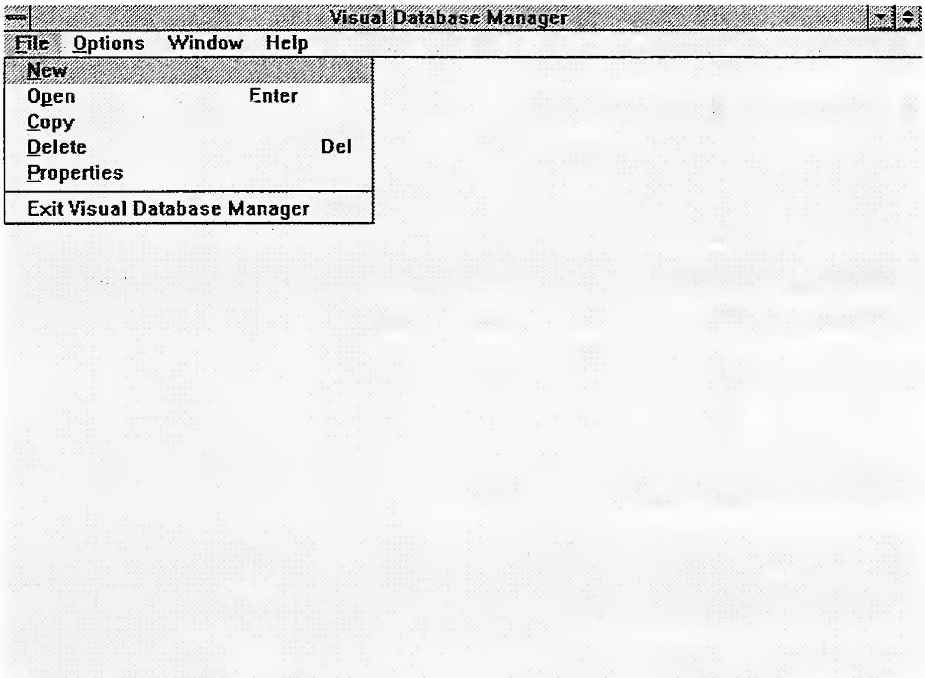


Figure 4.2 Visual database manager opening screen

From this screen, the user can access drop-down menus that list possible actions that are appropriate at a given time. This menu is oriented vertically, begins in the upper left corner of the screen display, and includes a Quit option.

This menu-guided dialogue is familiar to most engineers and preferred by novice and intermittent users. Also, in accordance with research recommendations:

- Complexity is low

- Redundant, or irrelevant commands do not exist

- Commands can be selected from the menus, or entered by experience users from the key board.

Novice users prefer a menu-guided dialogue, whereas experts prefer a user

guided dialogue. Therefore both menus and commands are available. Selecting 'New' at this point opens the screen shown in figure 4.3.

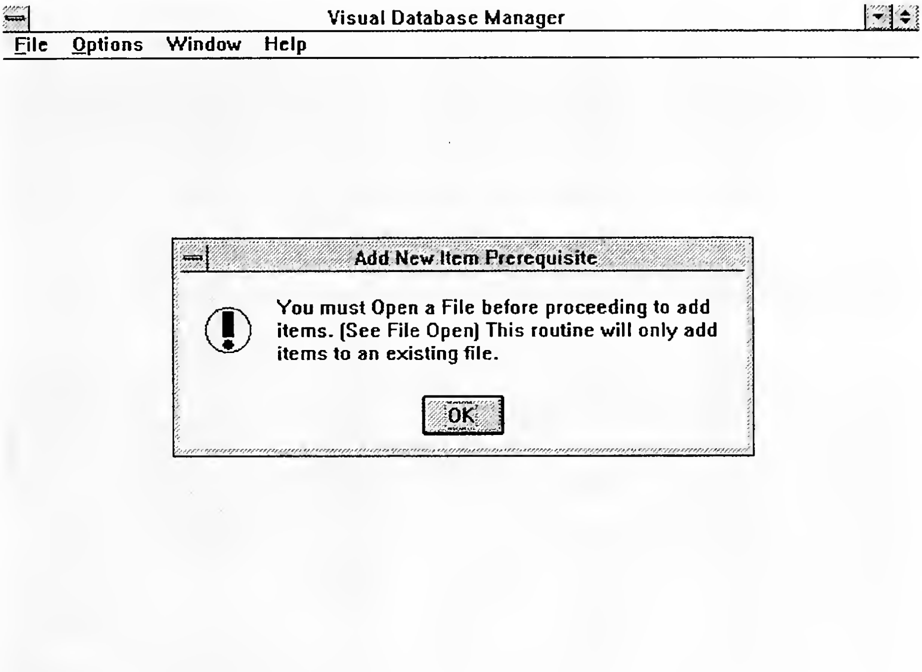


Figure 4.3 Warnings and errors

As recommended, error feedback is in close temporal proximity to the related event, such as when the computer detected that a data base had not been opened. (Selecting 'New', initiates a routine to add new constructability lessons learned or clusters of those lessons learned to a database. A database must be selected before such an operation is appropriate.) A computer-initiated system traps errors, and prompts or leads the user, and is therefore friendly to naive or casual users.

Error messages are specific and written from the point of view of the user, not in code. Upon acknowledgement of the error by the user (by clicking OK), the system automatically initiates the open database selection screen shown in figure 4.4, as if it had been initially selected.

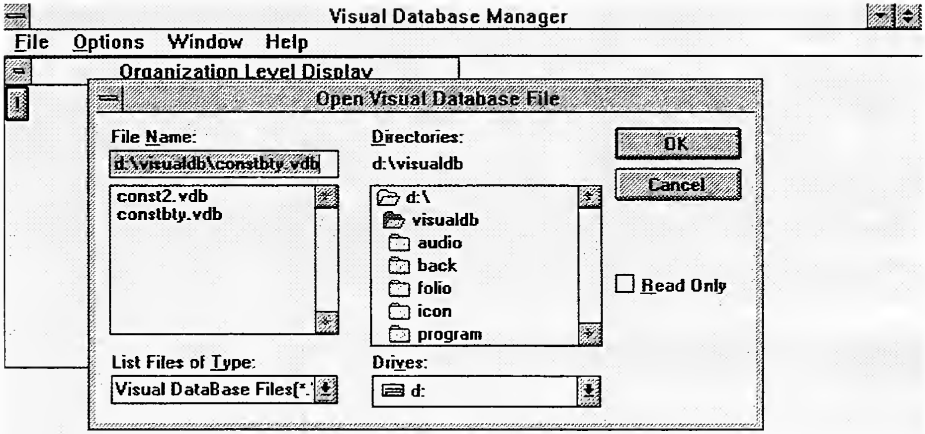


Figure 4.4 Opening a database

This is a very familiar presentation to Windows users, and is an ergonomically well designed screen. The most likely path and file are preselected and located by the system, and yet the full system search is available for advanced operations. The user must respond to the highlighted screen before proceeding, and direct user manipulation and visible results or the lack thereof, eliminate most errors or mitigates consequences.

Double clicking the appropriate database, or selecting OK initializes the visual database manager, opens and links it to the FolioViews electronic database, and displays the organization level cluster selection screen shown in figure 4.5. A cluster contains a group of lessons learned, or a group of lower level clusters. Opening sublevels or returning to higher level groups is done with the double click of the mouse on the appropriate icon. Organization level icons can be clusters of main or

detailed level clusters, or lessons learned themselves. Similarly, main level clusters may contain detailed level clusters or lessons learned. Detailed level clusters contain only lessons learned.

**Visual Database Search and Lesson Learned Selection**

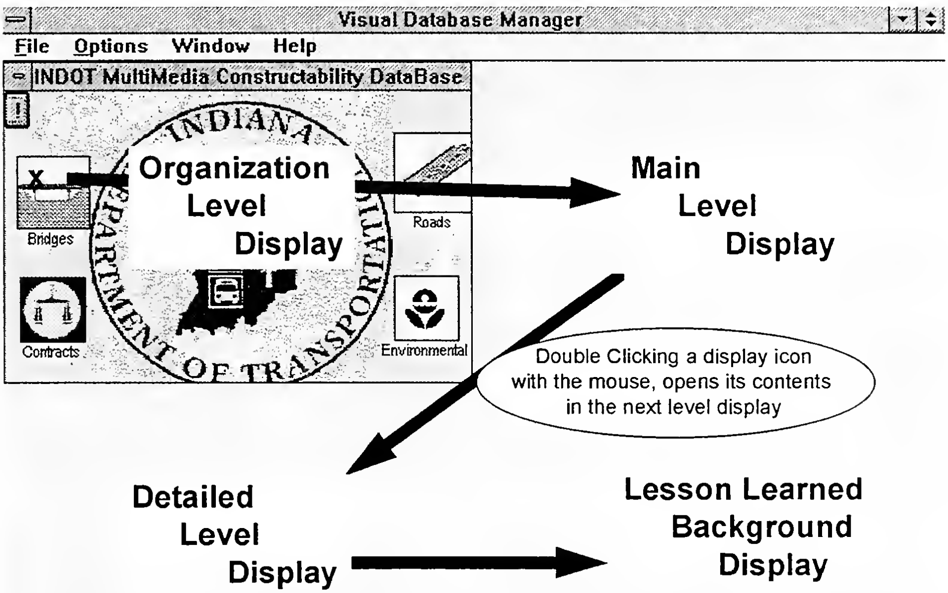


Figure 4.5 Organizational level display and database navigation

Navigation within the DICEP system is critical to its resourcefulness. (see figure 4.5) Roads, bridges, contracts, and environmental are four categories specific to INDOT's organization and naturally understood by its engineers. Icons representing clusters of lessons learned naturally categorized within these broad headings are available for selection with the mouse or key board.

These icons are mouse dragable and can be altered, reorganized or eliminated by the user. Double clicking on an icon (for example Bridges), opens its contents,

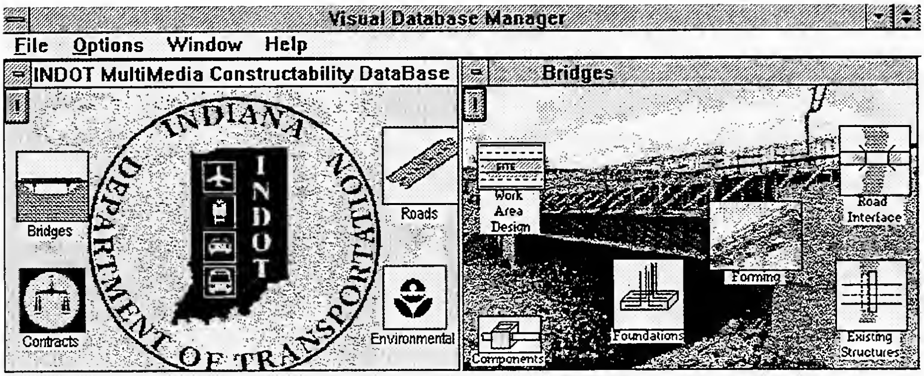


Figure 4.6 Main clusters

displayed on a related graphic background. (See figure 4.6)

Again, experienced users were found to prefer this type of user-initiated interface, with visual feedback to reduce uncertainty. The feedback helps to increase the speed at which they can make decisions. The meaning of graphic icons should be clear and conform to stereotypes. Thus the need to translate, interpret or refer to documentation should be minimized. This results in a system that is easier to learn.

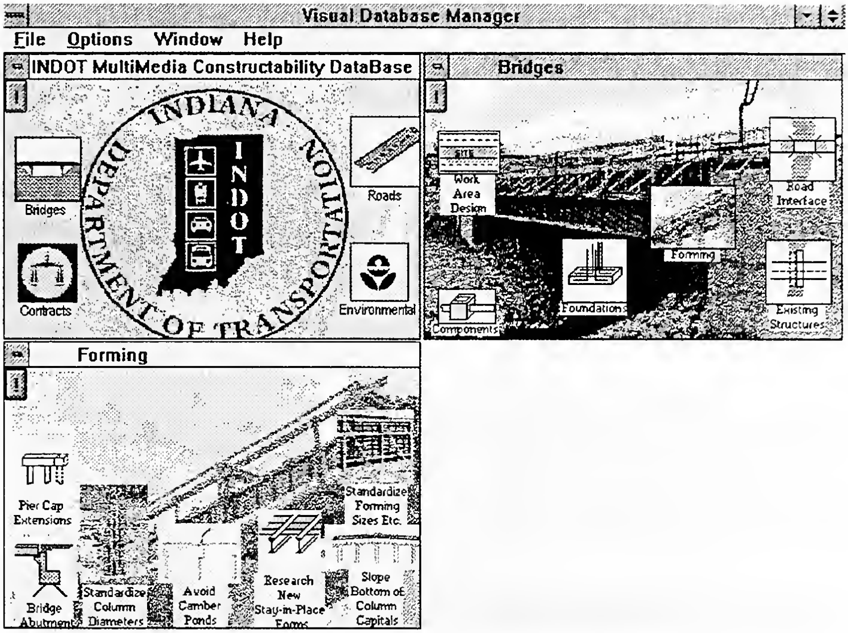


Figure 4.7 Detailed clusters and the selection of lessons learned

DICEP's structure is explicit through the use of spatial, graphical aids to depict the hierarchical organization of the database. Objects of interest are clearly visible, results of an action are displayed immediately and can be easily reversed, and actions occur by direct manipulation of physical objects, using a mouse. This will help the engineer to locate and answer a question at hand.

These icons and related backgrounds are easier to recognize, understand, and remember. This recall mechanism initiates the retrieval of existing knowldge into the working memory of the user, in order to prepair it to be assemilated with new knowledge. This process, naturally accomplished while finding a lesson learned is critical to effectively training the users. Thereby, actually using the system helps the user rapidly learn to behave like an expert.

Double clicking an icon on the detailed screen, selects a lesson learned. (Eg. Standardize column diameters, see figure 4.8)

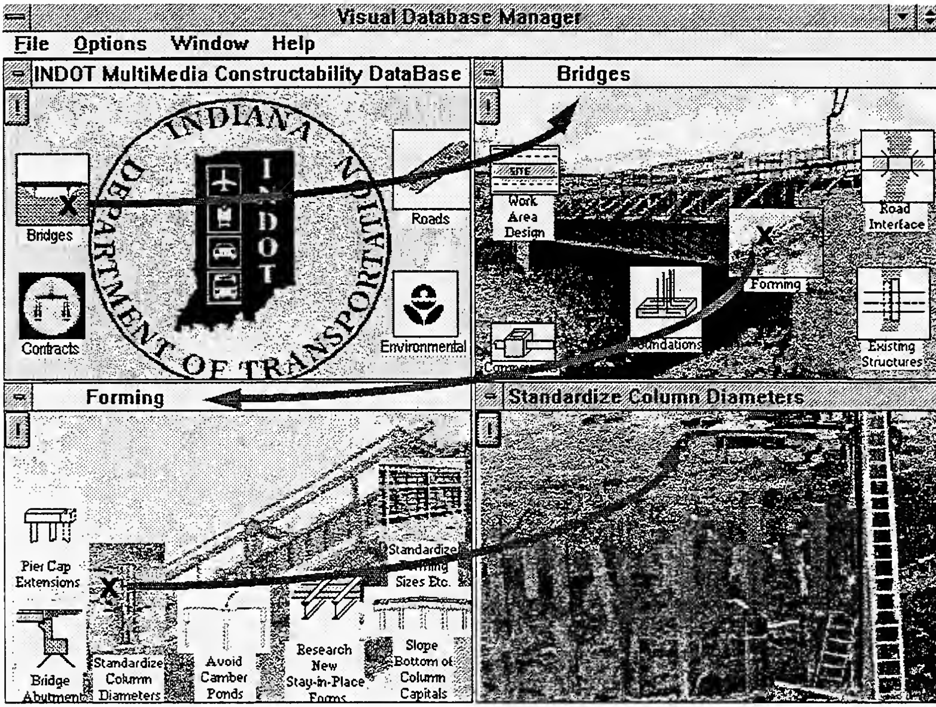


Figure 4.8 Lesson learned background display

This command-interface aids in organizing database content, allows reasonable learner-control options, promotes interaction between learner and lesson content, and simplifies lesson navigation. (see figure 4.8) The system matches the user's natural solution of the search task, and does not require learning a new system model. Consistency has been maintained between procedures. Keyboard commands for the experienced user to jump between procedures are provided. System behavior is predictable. Thus, previous experience with similar computer systems leads to ease of use and not difficulty in learning this new system.

DICEP also accommodates the learning process in a way that continues to deepen the understanding without becoming a nuisance. The content of previously reviewed lessons learned is likely to be recalled due to the richness of the selection procedure and icons.

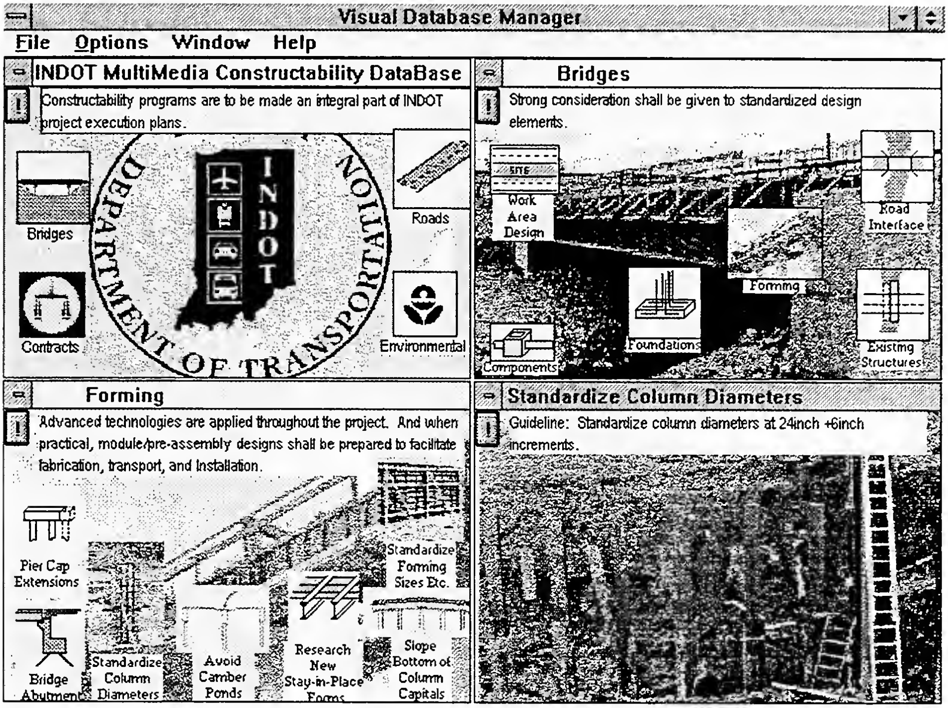


Figure 4.9 Concepts and lesson learned guidelines

These pop-up concepts (see figure 4.9), constitute low density text presentations, which contain principally the main ideas of a lesson learned, or cluster of lessons learned. This is an effective screen design technique for high ability users or users who are already familiar with lesson content. Such users may experience sufficiently rich cues at this point to recall the concept intelligence and need to go no further.

Further, low density text helps to cue users to important information and, consequently, may be effective for learning the main points of a text. However, low-density text may not provide enough redundancy for users with little conceptual background to support encoding. Therefore, such users will need to select (double click) the concept to gain this background.

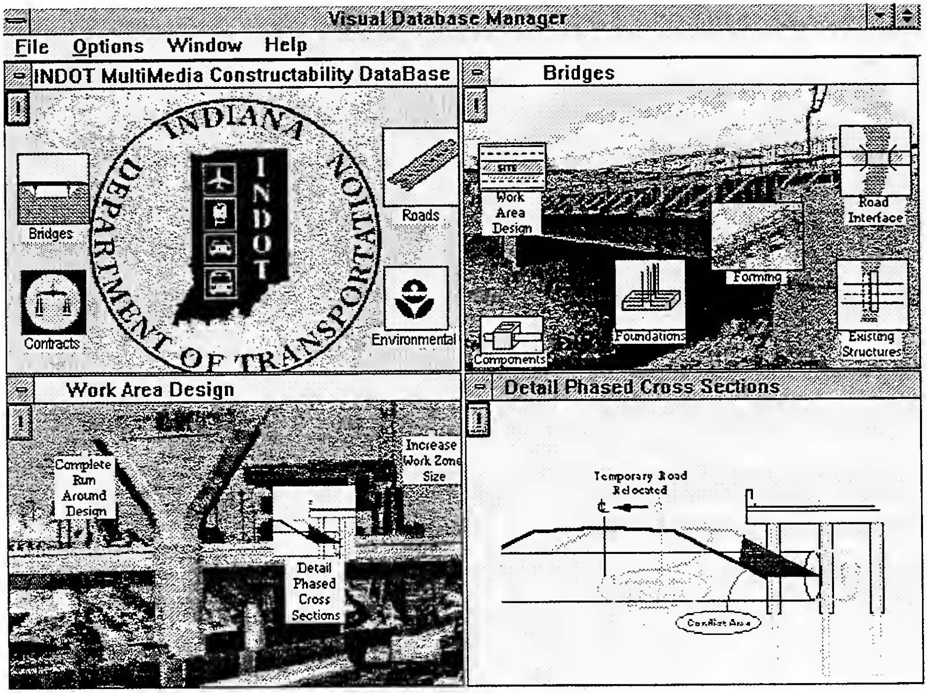


Figure 4.10 An example from Bridges-->Work Area Design-->Detail Phased Cross sections

Double clicking on Work Area Design and Detail Phased Cross sections creates the screen in Figure 4.10. Again the graphics with concepts and guidelines, help to cue prior knowledge by establishing relationships among key concepts and related information, and provide cues to facilitate recall.

Research has shown people like the objective and private advice from a computer based assistant. Double clicking anywhere on the selected lesson learned screen hyperlinks the user into that lesson learned within the Folio Views electronic database. (see figure 4.11)

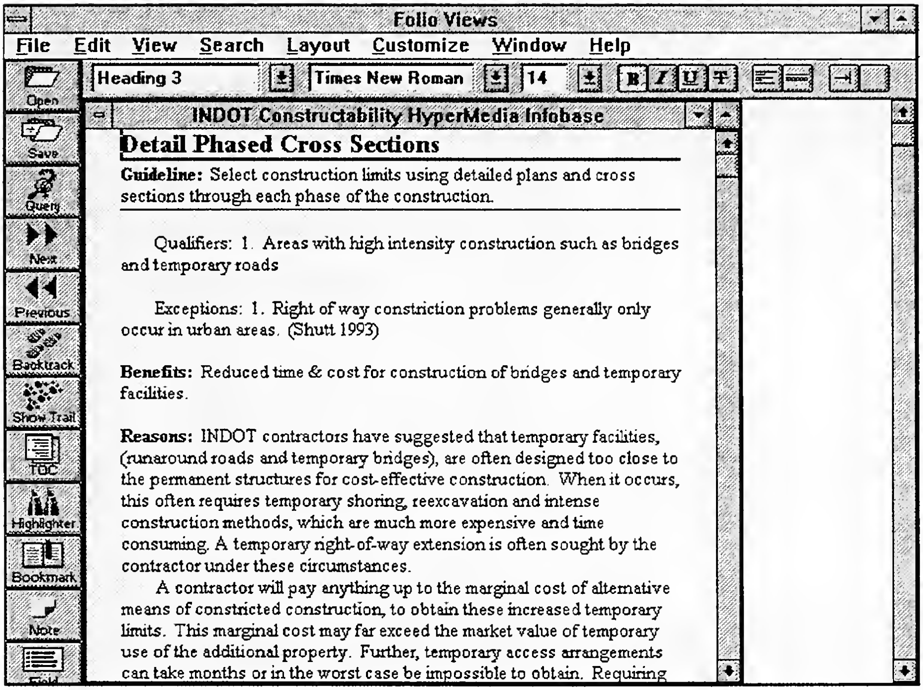

Figure 4.11 Lesson learned retrieval and presentation

The outlines and embedded headings, in the lesson learned, promote organization. The outline helps to establish a schema when previous knowledge is sparse. Headings, on the other hand, provide clear relationships between superordinate concepts and subordinate lesson content. However, headings may not clarify the relationships between superordinate concepts. Reasons and benefits, for example, establish the relevance of lesson information, which helps to increase engagement. In order for them to help, research has shown that users should be trained on the purpose of these headings and other cues.

Together, headings and outlines can establish a framework for interpreting content and connecting related information within that framework. Therefore, in addition to consistent headings, a pop-up outline should be provided at the beginning

of large or complex lessons.

The freedom exists within DICEP to use as many screens as needed. DICEP screens visually stimulate, are easy to read, and exhibit no annoying or distracting features. Proportional spacing allows recognition of words as a graphic chunk, rather than by assimilating the words, character by character. Left justification is used since varying spaces can also interrupt eye movement and slow down reading speed. The font type is common and the size large, to enable high reading speed and comprehension. Black print on a white background provides a good contrast in brightness.

Folio Views was chosen because it provided options which if selected, would create a display medium exhibiting many desirable ergonomic factors. Most of the remaining ergonomic factors identified during this research, were achieved by programming the visual interface described in figures 1 through 11. One which was not in either system is page formatting to eliminate the time consuming scroll. A somewhat compensating benefit is that a resized window can be set to automatically reformat its text to be readable as sized. This allows the system to be used as a help screen adjacent to rather than covering internal or external details and graphics. Although the appropriate size of the window must be manually created by dragging a side of the window, the user can then compare and contrast the constructability knowledge with the detail visible.

Once selected, a cue of lesson length, as well as the location within that lesson, is available by selecting to view the status line in Folio Views, under File --> Preferences.

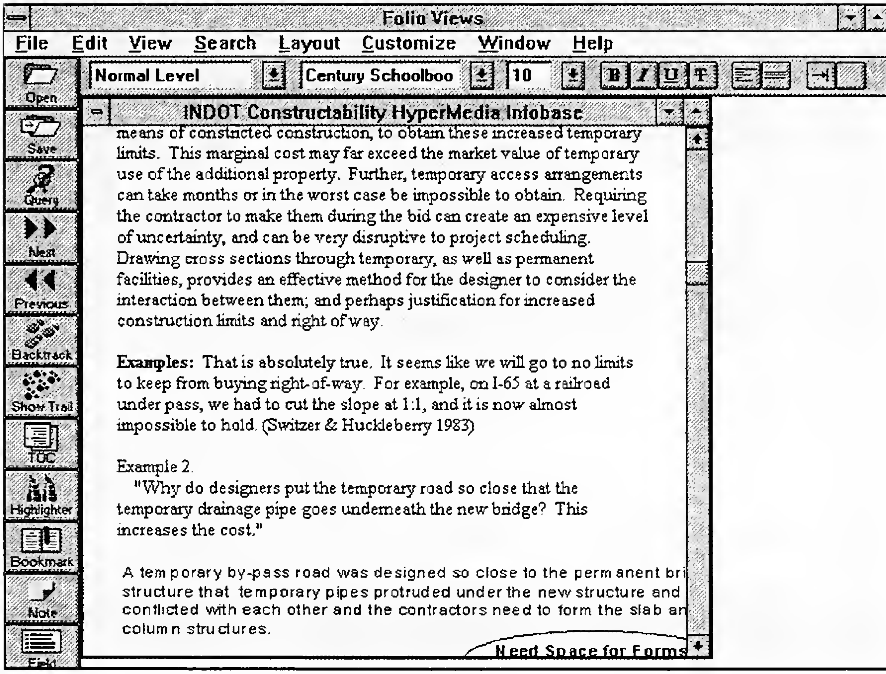


Figure 4.12 Presentation structure continued

DICEP provides access to a large domain specific knowledge base. This platform provides a medium to represent content knowledge ( facts and information), and process knowledge (how-to strategies). It can help a decision maker define a task environment that is composed of the objects and permissible actions relevant to the solution of a problem. (see figures 4.11 - 4.13)

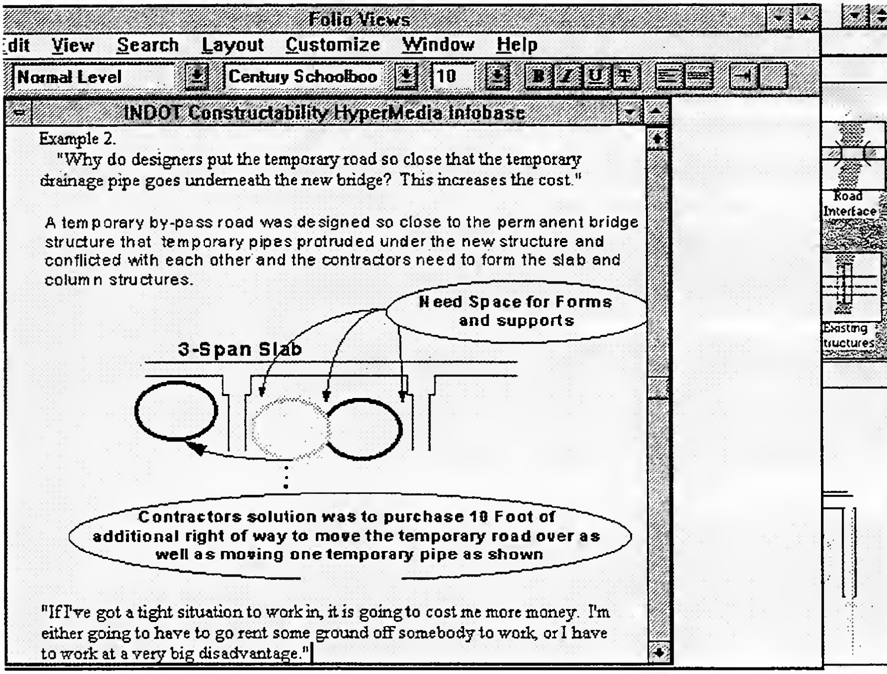


Figure 4.13 Presentation structure with embedded graphics

Lesson content, depth of processing during initial encoding, the availability and potency of retrieval cues, and the meaningfulness of initial learning all influence retrievability of lesson content, and are not limited by this platform. Retrieving involves recalling structures from long-term memory to be encoded with new information, which is to provide a framework within which new information can be assimilated. This screen design can further optimize integration of lesson content within existing knowledge.

Optimally can be achieved in DICEP through: phrasing text carefully, using continuity in text and graphics placement; removing unnecessary information from the screen, using graphics in addition to text when possible, using space appropriately to avoid overcrowding; and by using color and highlighting on a limited and consistent basis. (see figures 4.11 - 4.13)

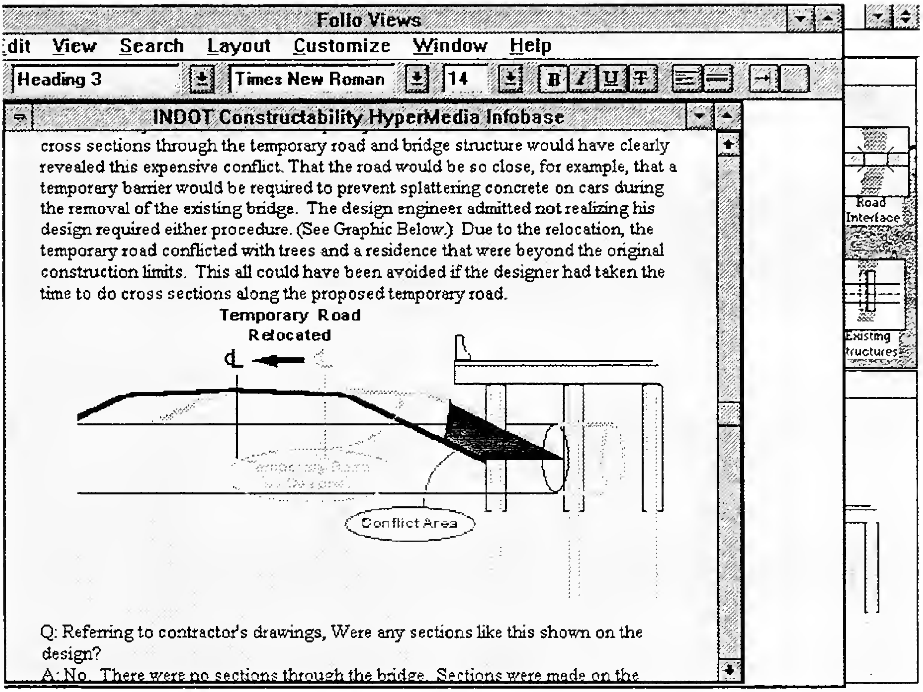


Figure 4.14 Graphics continued (and return)

Consistent amplification conventions (like color and font changes), can promote shifts in learner attention, and help the learner focus attention on key aspects of the lesson to deepen processing. Text and graphics should be combined only when extensive redundancy exists between the two sources. (see figure 4.14) Dual presentation of text and graphics may either strengthen encoding, if there is redundancy between the stimuli, or increase the processing burden if the presentation modes lack congruence.

Manually dragging the Folio Views window to the left, hides the Folio Button bar, which only provides considerable clutter during actual review of a lesson learned. (see figure 4.12 versus figure 4.13) To do so, also exposes the DICEP navigation system operating in the background. When the lesson is complete, clicking the standard windows-minimize button on Folio Views will minimize it and return the focus

and operation to the navigation Visual Database Manager, as shown in figure 4.15.

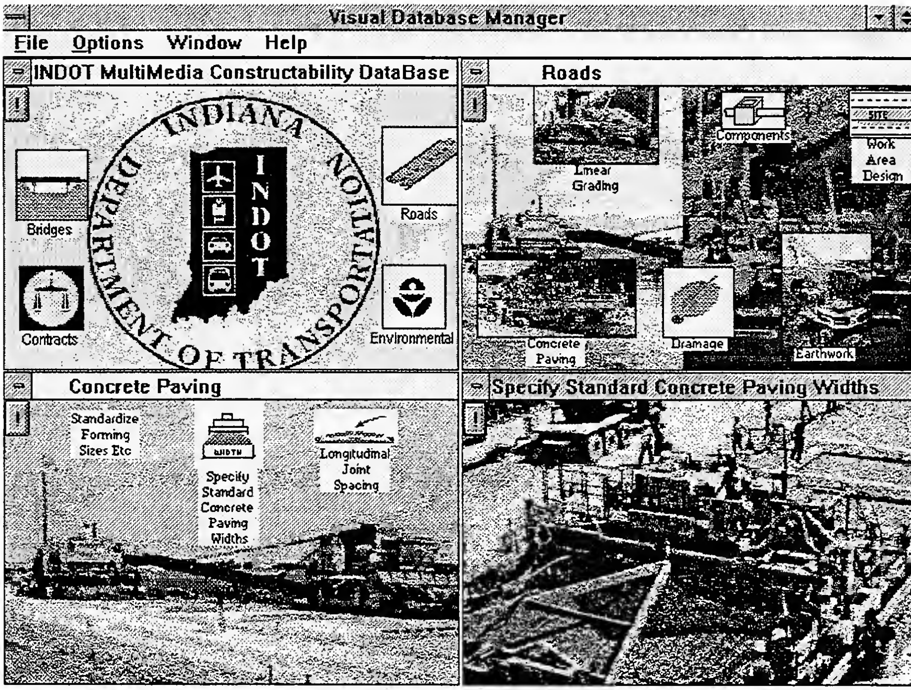


Figure 4.15 Another lesson learned Roads--> Concrete Paving --> Specify Standard Concrete Paving Widths

DICEP will enhance an engineer's use of good heuristic methods including:

1. Random selection by trial and error
2. Means-end analysis
3. Analogies that map well to the problem, and are easily retrieved
4. Logic and reason
5. For very complex decisions, the engineer can decide what features are important, selecting only those options that qualify, to be evaluated in more detail.

Knowledge that specific problems have occurred and designs to avoid them, will enable engineers to foresee and eliminate many problems before they are designed in.

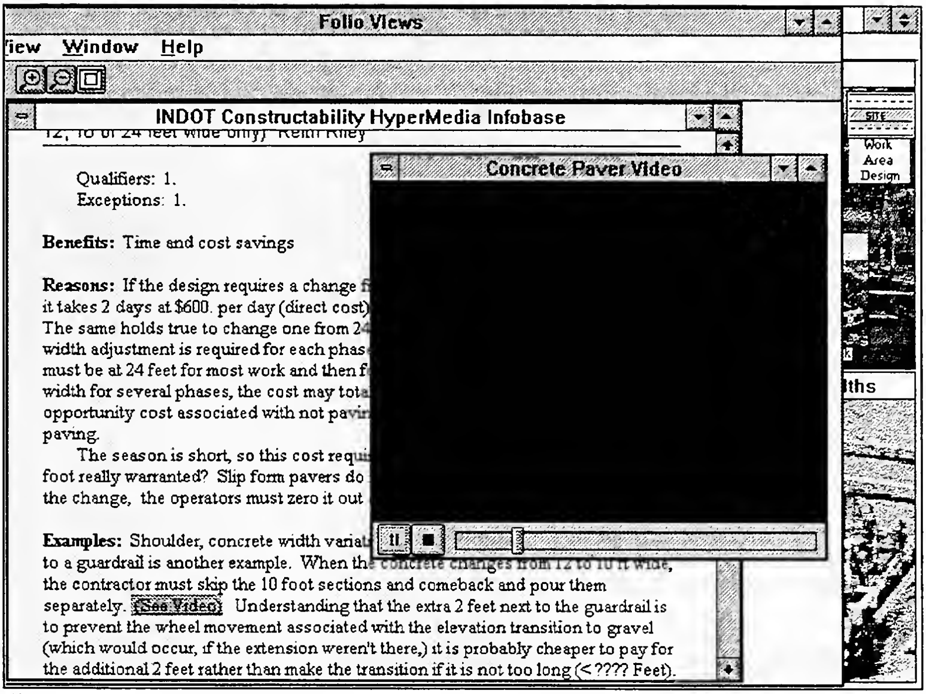

Figure 4.16 Linked video, and other object and program linking

The size of the pop-up video screen (shown in figure 4.16), is 5.5 inch wide by 4.25 inch high, on a 17 inch monitor. Many processes in the construction domain are more completely and easily explainable with motion. Video can help engineers to represent the problem at a deeper level and analyze problems qualitatively to get an appropriate representation before taking on a quantitative solution procedure. The full motion, video and audio clip can be paused, moved and resized, or jogged forward or backwards to reexamine the content.

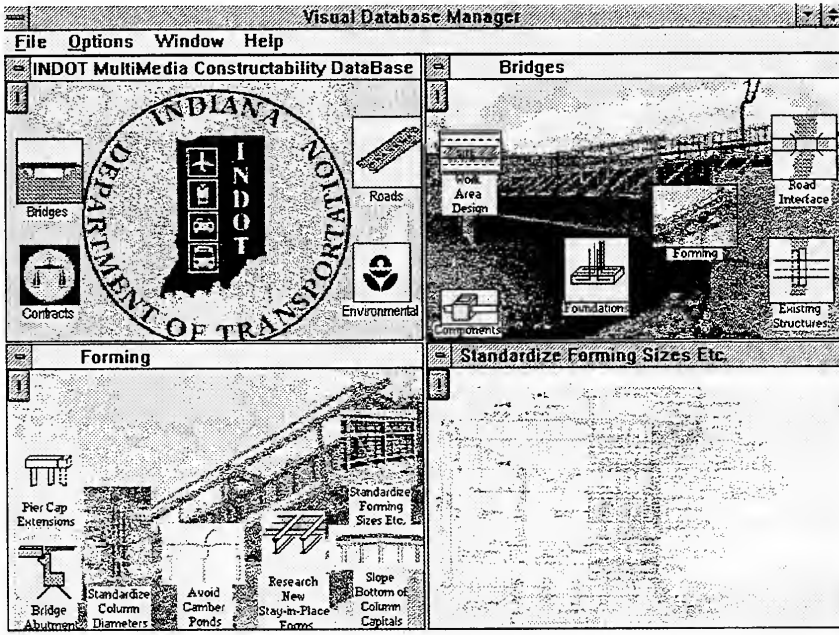


Figure 4.17 Another lesson learned with still graphics

Image quality may be important when details must be presented, but graphical techniques that intentionally obscure image quality, or decrease the vividness of an image, may actually deepen processing. For example, the forming design drawing represented in the lower right corner of figure 4.17 is not intended to be readable. It only brings the subject and related previous experience of the engineer to mind, in order to combine it with the new information to be presented in the lesson learned.

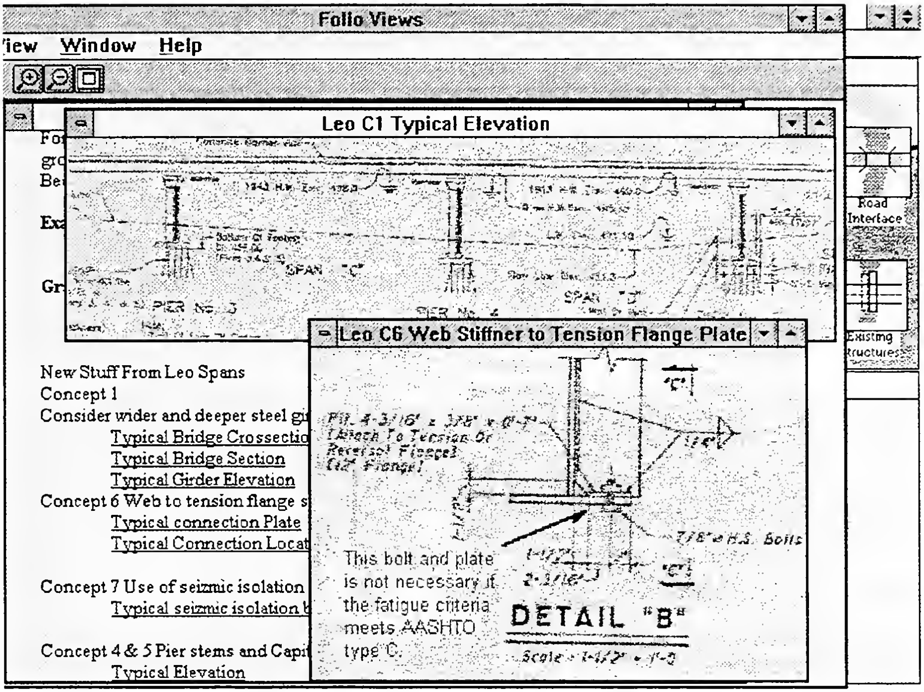


Figure 4.18 Moveable, sizable graphics

Pop-up windows are used for linked graphics. A double click on the highlighted link embedded in the text, activates it and brings up a graphic such as those in figure 4.18. They may be automatically sized to fit the graphic or page, and moved or resized by the user if needed to examine them more closely, or compare and contrast them with other text or graphics. They remain up until removed by the user.

To develop and maintain interest in the lesson content and activities, the presentation should promote enthusiastic learning. Photo Finish software was used to annotate and highlight specific areas of interest in these 24 bit images after scanning them from a blueline drawing. A sufficiently appealing environment is provided, that learners are inclined toward its use. Without initial and sustained lure to the activities contained in the lessons, attention and motivation may wane.

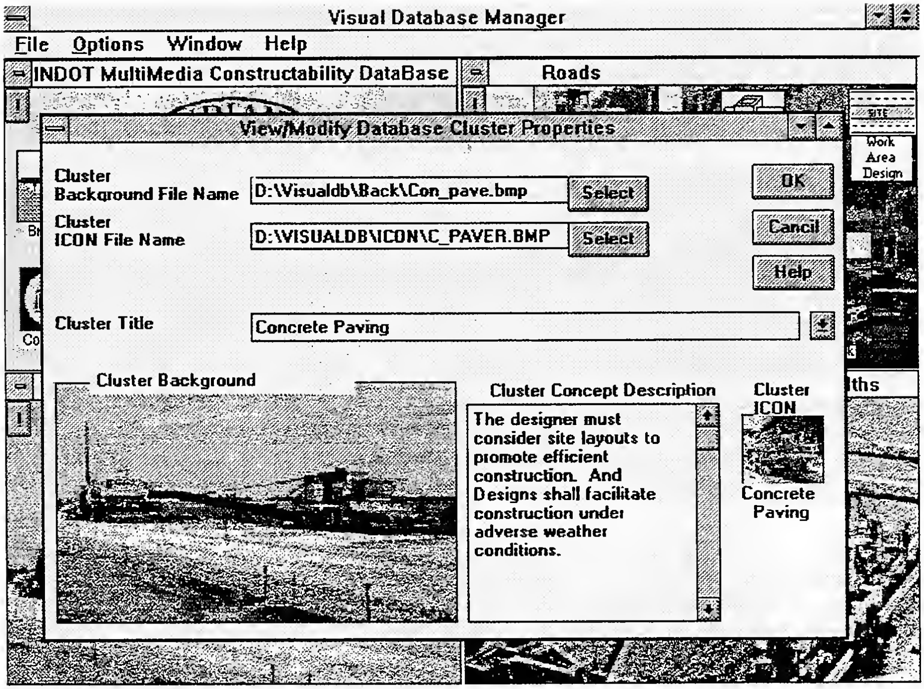

Figure 4.19 Altering and expanding the database

Individual differences stemming from language usage, problem-solving style, level of expertise, etc. among users can be accommodated through user tailoring of the DICEP interface. (see figure 4.19) The database organization and presentation can be easily customized by and for the user. Selecting any icon and then File --> Properties, displays the icon and allows the user to modify all its related properties. A new icon can be added is a similar fashion by selecting File --> New --> and then Cluster or Lesson Learned. Drop down menus and ordered lists make the addition straight forward and prevents most errors. Selected icons and background graphics appear on the properties window. And the text can be entered and altered directly from the keyboard.

The program is sensitive to the timing of error feedback. For instance, it is not

desirable to interrupt the user immediately upon detection of lack of input for a new program object. (The program waits until the user clicks OK.) In this process, users are aware at all times, where they are, what they have done, and whether it has been successful. Visual display feedback provides this assurance.

Error trapping has been or will be performed to eliminate any excessive negative consequences from user errors. The ergonomic principle being that the user should be given every opportunity to correct errors. Also, when the response to a user request will be delayed, an indication should be given that the request is being processed, (for example, the mouse icon changes to an hourglass, etc.). Otherwise the user may perceive that no action has been taken by the computer and reenter the request.

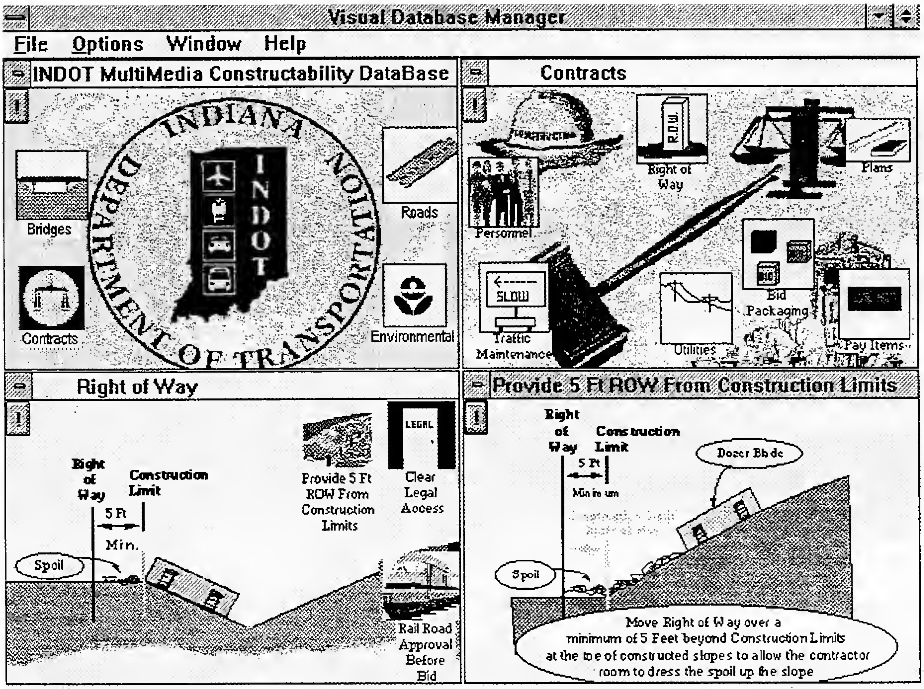

Figure 4.20 Memory recall from the visual database manager

Memory increases by more elaborate relation, and by increasing the depth of understanding. The learning context presented in DICEP matches up with the context required for remembering it. For example, see figure 4.20 for background graphics related to cutting or filling a slope next to a construction and right of way limit. Larger and more detailed versions of these graphics are used in the lesson learned. (see figure 4.21) They are used here to jog the engineer's memory of similar conditions they may be considering and perhaps to avoid the need to review it again. If the user proceeds into the lesson learned (by double clicking its background screen), the new knowledge will be more easily retrieved because it is encoded into long term memory in an elaborate fashion relating it to previously learned or known information.

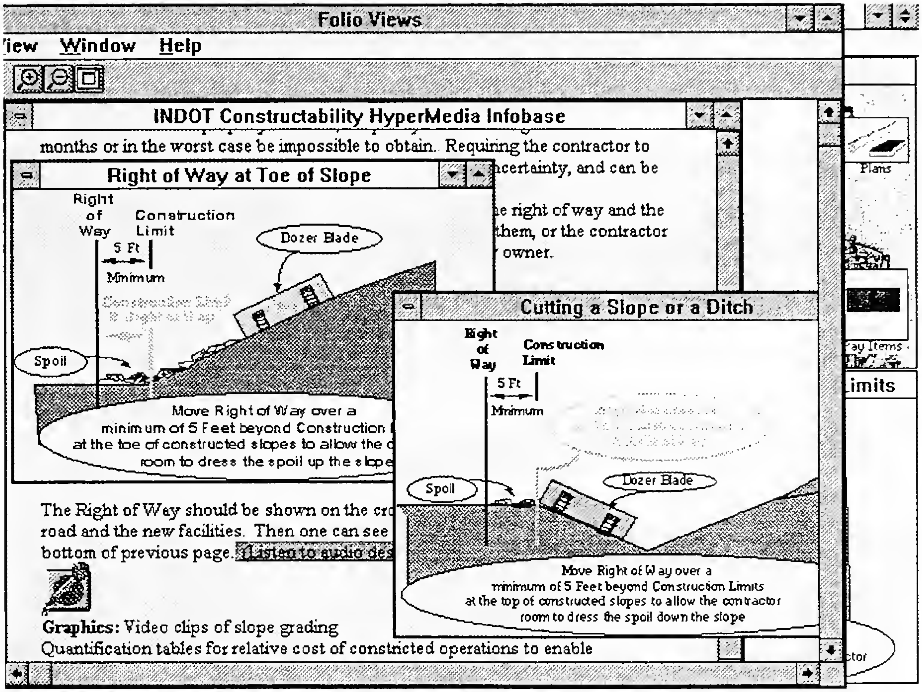


Figure 4.21 Combining audio and graphics

The richness of the encoding process dictates, in a large measure, the subsequent retrievability of acquired knowledge. If appropriately selected and presented as demonstrated in this prototype; the realism of 24 bit graphics, video and audio substantially enhances this process. (see figure 4.21) Double clicking on the microphone icon begins an audio explanation of the lesson shown in these graphics.

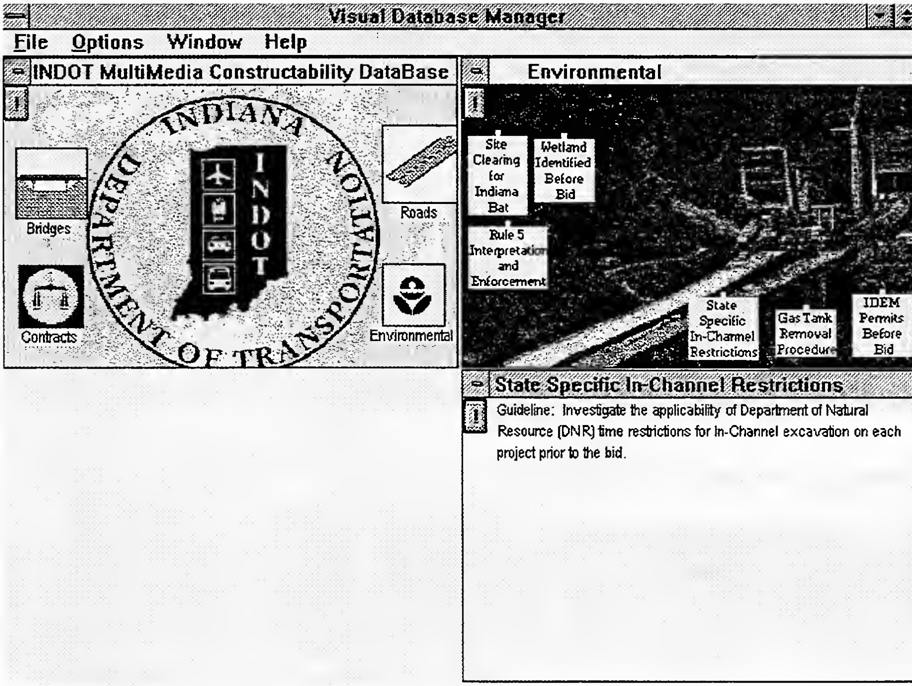


Figure 4.22 Interim development stages

Any, or all of the items suggested for inclusion in the system by INDOT and construction personnel, could be represented within, or linked to this engineering platform. Some lessons learned, for example those in the environmental area have no associated icon graphics at this time. The text description and a small blank icon provide access to this type of lesson learned. Figure 4.22 also shows the flexibility of organization within DICEP. Lessons learned, or icons representing clusters of lessons learned can be located at the organizational or main level. In this case no detailed level exists for the 'State Specific In-Channel Restrictions' icon, so the lesson learned screen appears directly from double clicking the main level icon.

As an enhancement, an expert system could query the user and provide suggested review items for consideration, training sequences, or create a new permanent cluster, if desired.

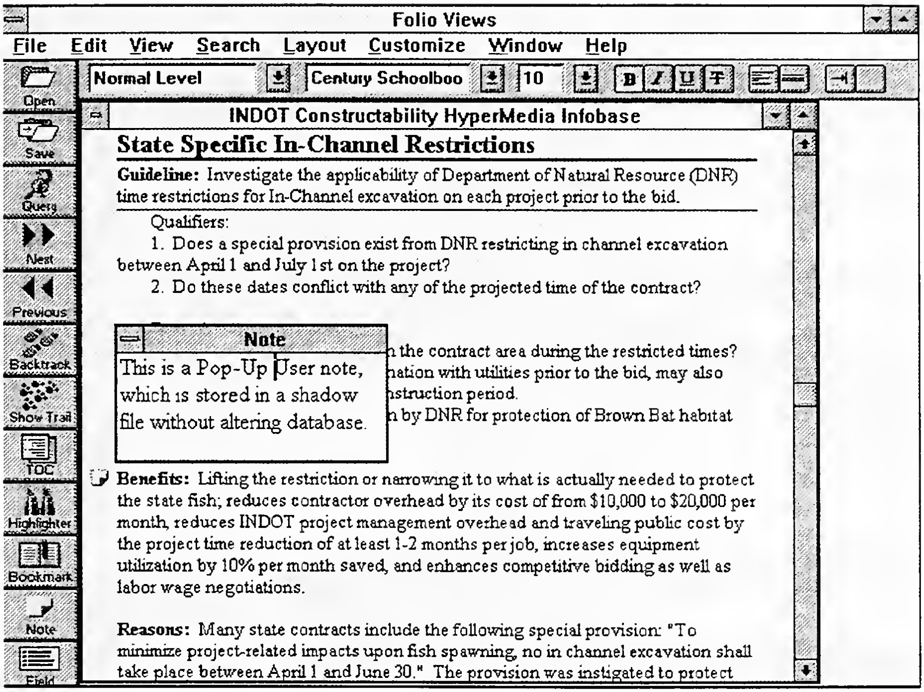


Figure 4.23 Deepening the memory through user customization

Personalized interpretations of lesson concepts by on-demand annotation, elaboration, or summarization will improve both the meaningfulness of the learning and the level of integration of new with existing knowledge. As shown in figure 4.23, the option is provided for users to highlight text, and to create electronic notes on the computer during instruction. Research has shown that this increases both the amount and depth of processing.

Hyperlinks between concepts or to other databases or programs, are also easily constructed within DICEP.

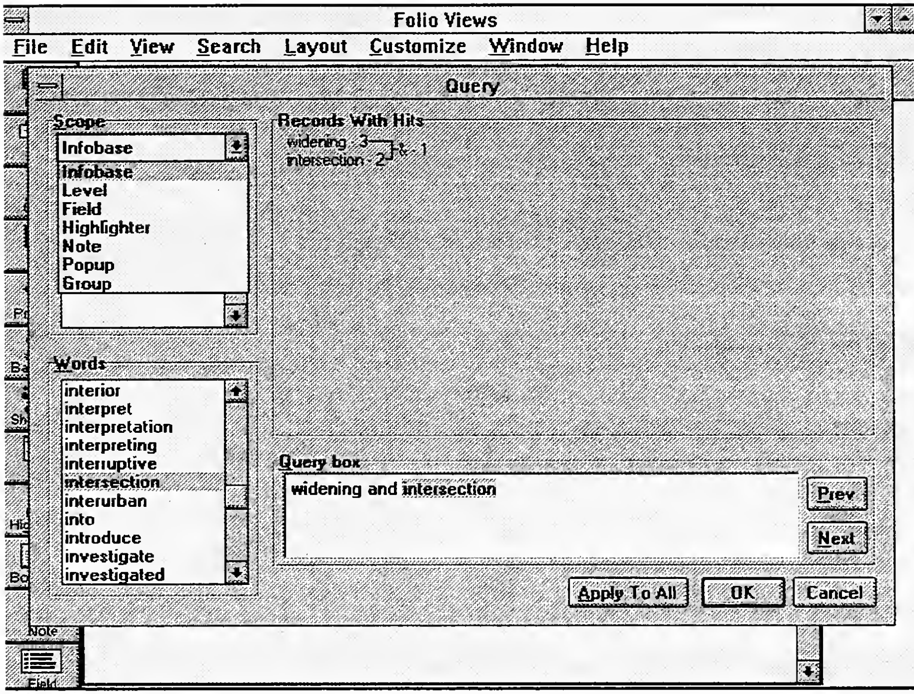

Figure 4.24 Hypersearch

The Folio Views natural language search system (shown in figure 4.24), is similar to many state-of-the-art library retrieval systems, which will take advantage of any existing familiarity. Searching power and enhanced user friendly characteristics of this interface were primary factors in the selection of the Folio electronic publishing system. This system catalogues and lists all words contained in the database (see lower left window). In this interface, the user is guided through the construction of a natural language search command, and the potential results of valid, or imprecise requests are clearly visible. Research has found people naturally restrict vocabularies and perform adequately with such a restricted subset of words.

The search can be limited to specific infobases, notes, or user highlighted text (see upper left window); or expanded with a thesaurus, word stemming, and multiple

databases. Powerful boolean algebraic statements with ( ), or, and, not etc. can narrow or broaden a search.

**Summary of DICEP Programming**

DICEP has been designed to serve as a Construction Engineering Platform for integrating constructability principles during design. To do so effectively, the majority of recommendations resulting from the presented human factors research have been incorporated into the design. Conclusions and recommendations for using this program to enable this infusion of constructability principles into the INDOT design process are presented in chapter 5.

# CHAPTER 5
# CONCLUSIONS AND RECOMMENDATIONS

## Summary

### Lowers Project Cost

Using DICEP during the planning, conceptual and schematic design phases, will significantly reduce construction labor and equipment cost. It will also decrease the amount of change orders, help prevent cost overruns, lessen scope growth, and most likely minimize claims, time extensions, and litigation. With this system the human design engineer is effectively involved in the implementation of constructability during design, not replaced by an expert system. This can enable designers to complete their understanding of the cost equation, which has to this point been largely based on optimization by material quantity reduction alone.

### Enables Locating and Educating

It is desirable to change from the standard review mode to a design that includes constructability principles in the first place. This requires a correct understanding of appropriate principles, and their related importance, in the working memory of the design engineer at the key point when the correct decision needs to be made. DICEP is an environment suitable for user-directed navigation, and ideal for encoding of appropriate information into the long term memory. In it, the engineer can bring into the working memory as much related existing knowledge as possible, and a deep, elaborate synthesis of the new information with the old can take place. Within this framework, multimedia technology can enable both the recall and synthesis to occur with a broader and deeper scope than text or printed material alone.

DICEP can be effectively used to locate, explain and educate; to create a bridge between the expert committees who develop standards and the relatively inexperienced design engineers who must use them. It links the user to standard construction process clips for the designer to see first hand the problems that their design or detailing can lead to, and enhances the designer's experience about construction methods. This can make constructability knowledge available, at an

appropriate level of detail, at the right time in the design process.

Involving the human successfully, usually requires some assistance in recalling appropriate knowledge to be considered in a decision. To be efficient, DICEP presents new knowledge in a fashion that can be elaborately related to prior knowledge, and thus passed to the long term memory in a retrievable fashion. Thereby this system eliminates the need for its repeated use on the same lesson learned, and enables the inclusion of constructability concepts at the point of design. The following sections describe some of the features and capabilities of DICEP, from the prospective of user needs.

Eliminates Construction Related Design Errors Before They Occur

Rather than reviewing plans and specifications after the design is complete, using DICEP, the integration of construction knowledge and experience is possible in the earliest stages of project planning. Designers need not risk public acknowledgement of defective design documents, but can seek the private advice from their computer assistant while design decisions are in the early stages. Professional pride is retained, and the time and cost to make substantive changes, to include constructability, are reduced.

Designers need not rely solely on their own site experience, combined with bits and pieces of constructability knowledge published in various places, or on input from a friendly contractor. An explicit constructability knowledge base is economically feasible to create, update and use. The designer can see first hand the problems that design detailing can lead to, and be exposed to the full range of methods that may be utilized by contractors. A large individual investment of time and money is not required. As a result, owners need not pay the additional price for design-rework, which is less costly than construction-rework, but occurs too late to influence the major construction methods.

Without the designers professional reputation at risk, construction experts, involved in developing the database, can comment objectively without appearing overly critical. The need for the involvement of qualified personnel, with direct

construction experience on similar projects, as well as experience in working as a member of an integrated project team, is reduced.

## Enabling Technology for Artificial Intelligence Modules

It is anticipated that the technological and economic feasibility to represent constructability, and other forms of value engineering knowledge, in an artificial-expert environment will improve. The ergonomic interface and hypermedia representation herein proposed will augment and even facilitate ongoing development of these systems. Indeed, when an intelligent system can review and identify violations of constructability principles and even synthesis solutions, it will still be necessary to effectively assimilate such knowledge into the existing understanding of the responsible engineer. Concepts, reasons, exceptions, quantifications and examples will be required to enable such a technology transfer, and to enhance the current and future decisions. It is this need to bridge the gap between what is known and what can be automated, as well as explain the results of automated evaluations that DICEP will fill.

Through the careful and systematic application of human factors during the design of the DICEP interface, the human engineer can be retained in an active and productive role. This interface will enable the human to economically evaluate a problem, which may be evident or represented in a multitude of different text or graphic formats. Representing the problem and the logic for its solution in a machine readable format, are not required. Thereby, a wide variety of problems, including those with far less repetition than required to justify automation, can be economically represented. Further, a more comprehensive and usable design platform can be provided. All identified constructability concepts and lessons learned can be described in the DICEP format. And expert systems or other forms of automation can be systematically added, for specific functions, when it becomes economically justifiable to do so.

DICEP Fills the Ergonomic Interface Void

Without appropriate use of multimedia, previously developed systems haven't even approached the limits of what human perception and cognitive processing can achieve. Rather than attempting to replace the design engineer, DICEP provides an ergonomic way that technology can enhance and improve his capacities. Heuristics are the natural decision making processes which DICEP accommodates and enhances.

DICEP is still in the formative stage and will now proceed into user evaluation and BETA testing in the next project phase, " INDOT Constructability Multimedia System Working Module.". This next stage of development should include a routine for system fault detection, recognition, and actions to recover the system. It is structured and modular, and makes use of pretty print, extensive comments and mnemonic names, and other characteristics of state of the art programming. Recommendations, which will further enhance the effectiveness of DICEP in the INDOT design setting, are presented in the next section.

## Recommendations

Constructability is not a replacement for sound design or project management principles, but is an extension and reinforcement of such principles. Furthermore, it is important, especially in the development phase, to consider the use of DICEP as reducing rather than replacing the need for involving construction personnel during planning and design.

Innovation

DICEP can link users to external databases to help designers in selecting construction materials and methods that are beyond their experience and training. Before DICEP, an effective platform had not been developed to provide access to many developing databases in the construction domain.

The immediate result of setting up this constructability program will be product

and process innovation. This will occur due to the heightened availability of a broad source of information. The environment to accommodate this within the INDOT organization must be created, including timely evaluation, preestablished procedures and approval/recommendations for carrying out lessons learned. Problems, for example change orders and other recurring situations, etc. can drive innovation, but the availability of new technology can also drive it, and INDOT must be prepared for change.

### Provide Multimedia to Paper-Contract-Document Transition

Hypermedia can be effectively used to explain and educate, but a design is still communicated with text and drawings. Therefore, each lesson learned should provide a transition to show how to actually implement the concept into a drawing or specification.

### Individualization

Human behavior with computers is characterized by individual differences stemming from language usage, problem-solving style, level of expertise, etc. These differences among users can be accommodated through automatic adaptation or user tailoring of the interface. (Williges, Williges, & Elderton 1982). McCoy (1983) suggested a user knowledge base model that is continually updated during system use. A set of domain dependent heuristics is then used to determine what is wrong with the users information and what faulty reasoning led to the user's use of that bad information. Another form would be to provide suggestions in the absence of a request from the user. An expert system could suggest training sequences for new engineers, query the user and provide suggested review items for consideration, and create a new cluster of such lesson icons.

Another expert system could be developed to enable project participants to view construction alternatives and associated costs related to characteristics of a specific project. It could also be used to record and track constructability cost and schedule savings, in order to justify future development of the program.

Provide Incentives for Expansion and Use of the System

Consultants should be required to present their qualifications during the selection process for new work. At this time, they should be encouraged to describe how they plan to incorporate existing constructability principles; what new ideas are applicable, and what additions, depth of analysis increases, and new examples could be added to existing constructability principles. In this way the consultant becomes a more active and visible source for further depth and understanding of alternatives.

Refocus on the Knowledge Base

With the DICEP interface well into development, it is appropriate to focus future efforts on the knowledge base itself. The bulk of future work in this area should be toward the extraction of knowledge, coordinating solutions, representing the knowledge in multimedia or rule form, and finally the testing and validation of the knowledge base. INDOT should create a concept development task force of appropriate experts for each category of lessons learned to:

1. Evaluate lesson relevance, content and increase depth
2. Identify clusters, icons and background graphics
3. Create clusters for new engineer break-in training
4. Identify additional research where needed

Beyond familiarity with the principles contained in this report, those collecting multimedia data should also receive some technical training to capture high quality still and motion photography.

**Recommended Modules**

Innovation Module

A DICEP database could be created to store article clips, case studies, seminar intelligence, or random ideas; items not directly approved or applicable to current problems or work, but in related engineering and scientific domains. To keep development cost low and quality high, they should be stored in original context, or compressed by an expert. A scanned image of the article with an attached unedited

ASCI file, produced by optical character recognition, could be accessed in DICEP by Folio Views natural-language word search routines.

Design Manual

DICEP links into and from the design manual are important. Such links could be developed from manual searches of the database.

Standard Details and Specifications

Constructability intelligence related to each standard detail and specification section could be developed by experts and stored with that detail or section in a hypermedia linked document file. Again manual searches by an expert could reveal appropriate links to the constructability and other electronic databases. Periodic updates should be performed as the database expands.

Equipment Utilization

A multimedia module that explains the utilization, requirements, and capabilities of construction equipment. This module could be used by designers to improve their understanding of construction operations, the required equipment needs, and construction methods and techniques.

Maintenance Considerations

Incorporating maintenance considerations into the design has very importatnt life cycle implications. There is a stong tendancy in design to focus on the initial cost and less on the overall or life cycle costs. High maintenance costs can offset lower construction costs so that for the life of the facility the design is not economical. A module that captures and provides this information to the designer would be useful.

Expansion and Continuous Updating

DICEP content development must be ongoing, staffed and assigned resources, have clear guidelines for operations and procedures and responsibilities, and must

become an integral part of the organization management. Care should be taken to assure that functions are sufficiently detailed to specify precisely what is required. For example, some will need to monitor or gather information and transmit it to others. Some will simply need to be informed while others will approve or direct an action to be taken, etc. Input suggestions should be taken from anyone, but reviewed for completeness & accuracy by:

1. the constructability specialist and/or
2. a committee or technical specialist selected by him.

This system should be developed so that every lesson learned is available for use as soon as it has been developed and approved. This can be accomplished by publishing the database from time to time on CD-ROM, and sending interim updates to a large (500 MB or larger) hard drive on each user PC, via modem and standard telephone line transmission rates. When the new data volume justifies a CD update, it could be made.

**Future Research**

Future research in this area should again focus on adding content and quality to the constructability and related databases. Statistical user testing could be performed to evaluate alternative selection-icons, concept descriptions, and lessons learned; to be sure they include the proper content depth and presentation mediums. Contained within the 'utility' and other complex lessons learned, is the need and opportunity for several expert systems and further research to identify the best alternatives. Ongoing need for research to take advantage of the cutting edge of available technology is suggested in the following sections.

<u>Natural Language Processing Systems</u>

Full text search systems use any natural language group of words, paragraphs or documents, as the subject identifier, to search for other documents. They can incorporate thesaurus, user-defined-related-key-word lists, and stemming algorithms to

expand the search to include words with similar meanings to those specified by the user. Such systems can seamlessly scan documents stored under a wide variety of platforms, networks, operating systems and word processors, without the need to transform them into a retrievable format. It can then statistically rank the documents found, according to frequency of congruent words, presenting the most likely at the top of the selection list. The use of these systems to extend the search to external databases should be investigated.

Further, the availability of fuzzy neural networks opens the door for even more powerful natural-language-database search algorithms. Through this technology, the development of automated systems for suggesting hyperlinks both within and between databases is, or will soon be, technologically feasible. It may also soon be feasible to automatically monitor intelligence on and around the design work station, extracting key words, phrases and even concepts, to continuously select appropriate lessons learned for consideration during design.

## Knowledge Extraction

Rocha et.al. (1992), demonstrated the use of fuzzy neural networks to identify and extract words, phrases & concepts from natural language databases. During this process, a fuzzy neural network is created for each substantially unique word, phrase, and concept in a processed database. These nets are strengthened and fuzzified by variations of these words, phrases and concepts, and a new net is created for entirely different items. Once generated, these networks can be used to automatically compare large natural language files and propose hyperlinks for expert evaluation.

This could be done, for example, between the constructability concepts file and the design manual. Algorithms to perform this function, have been proposed and tested on natural databases similar to DICEP, but are not currently rigorous enough for field use. (Alegre, et.al. 1993)(Morooka, et.al. 1993) This technology could also be used to automatically analyze a continuous influx of design intelligence, from auditory and optical input, to propose concepts for review in real time. With this technology in hand, and following the development of strong interstate constructability

system hyperlinks, the potential for expansion to national and international electronic constructability concept searches and database links, should also be investigated

**Costs and Benefits**

This can be an effective tool for designers to incorporate construction experience into the design product. For it to be successfull, it must maintained by INDOT. Maintaining will require personnel and cost money. It is estimated that this will require two design division engineers(one full time and one part time), and one part time secretary and some multimedia supplies costing the Department approximately $100,000 annually to support.

Benefits associated with using this tool can be quantified by using general cost saving ratios experienced in the construction industry or with a more specific estimating process. CII research reveals a cost savings range between 6 to 23% of construction costs through constructability programs. For INDOT with an annual construction budget of $450 million, this translates into estimated savings between $27-$100 million. A more specific cost savings analysis was performed for some of the lessons learned identified in this study. Only lessons that have been sufficiently developed were analyzed for cost savings and two values, minimum and maximum, were calculated. This information is grouped by the four main areas of Bridges, Roads, Contracts, and Environmental. Only the first two have calculated cost savings based on INDOT unit prices and this information can be found in Appendix D.

**Final Note**

What has been demonstrated here for integrating constructability knowledge into a transportation design department can, with appropriate modifications, be made applicable to many other disciplines and organizations. A CAD program could be modified to include a context sensitive button access to DICEP. Such a system would reference selected design details within CAD and hyperlink the user to related constructability knowledge in DICEP. Further there may be significant benefit to including concepts in the knowledge base to train construction personnel about the design process and how and when their input could best serve the needs of the traveling, tax paying public.

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Appendix A: Summary of Background Interviews with INDOT

**Summary of interviews held by the author on March 10, 1993 with David M. Pluckebaum Chief, Division of Design and 5 Unit supervisors at INDOT.**

Interviewees INDOT

| | |
|---|---|
| **David M. Pluckebaum** | Chief, Division of Design |
| **Mark Zwoyer** | Unit Supervisor - In house Bridge Design |
| **Mary Jo Carptnter** | Unit Supervisor - In house Bridge Design |
| **Hasmukh Patel** | Bridge Replacement Division Chief |
| **Jim Karr** | Bridge Rehabilitation Supervisor |
| **Dave Henkel** | Signal Design Engineer |
| **Joel Meyers** | Sign Design Engineer |

Interviewer - Bob Patty

## Goals

Although my intent was to perform unobtrusive observation of actual design processes, my host, Walt Land felt that I would not learn much from such an observation technique and had set up meetings with the above design management personnel for interviews. Therefor, I conducted unstructured interviews with these personnel to discover the following:

1. A general description of the design process used at INDOT, including:
   - Structure of the project flow through the system
   - Available design resources for the implementation of design and constructability principles.
   - Department organization
2. Training programs for new engineers
3. General level of experience of design engineers
4. Feedback mechanisms for field experience
5. Mechanisms to record and disseminate constructability data from field experience.
6. General feelings about what should be included in an intelligent multimedia system to make the greatest impact on the inclusion of constructability principles during design.

# Results

**Current Resources for design:**

Indiana Department of Highways Standard Specification, 1988
Professor Lee's programs for structural design
Book of standard details for bridge and highway design.
HEC 2 Hydraulic design system
FHWA Analysis system for traffic
BAMS Manual for contracts cost estimating
Video log of entire state transportation system. Allows a design engineer to avoid most field visits by providing a video taken of each side of the highway from a moving vehicle.
GDS CAD graphics design and detailing system. Ref Jeff Wright at Purdue has a Work Station, as does Bill Holloway of Graphical information services.
Jim Karr's 'goodie file' of lessons learned for bridge rehab.
Interoffice detail notes for explaining lessons learned.

**Resources currently being developed:**

A new 7 volume design manual being composed by an outside consultant, and due out within 2 years (a date which continues to move out)
A CAD based computer program for design detailing of 3 span, cast in place, flat bridges. Author Mary Jo, nearly complete. Will handle ~85% of in-house design cases.
- Won't handle Superelevation, military loading with more than 600 trucks/day, other than WGB guardrail section ends.

Entering into CAD all details in the book of standard details for bridge and highway design. See Paul Schmidt.

**In house design organization:**

Supervisor - 10+ years Exper. Responsible for General Mgmt.
PE - 6-7 years Exper. " for Technical Supervision
PE's, EIT's & young engineers " for Design

**In-House Design process:**

Begins with a preliminary Engineers Report
- Sets type of structure steel beam, post tension concrete etc. Design engineer can change but must clear any impact on the budget established in the preliminary report.

Pick a bridge type
- Options include Steel I beam, slab & beam, post tension beam,

prestressed beam & flat slab.

Steel beams are usually built-up sections rather than hot rolled due to the economies provided by the flexibility of a built up section.

Prestressed ~40% @ \$55.00/sf ave

Straight slab ~60% @ \$45.00/sf ave can use for up to 110 ft, 3 span bridge. ( mid span of ~45 lf)

Arranges for detailed survey combination of ground and areal

Design engineer annotates the preliminary bridge plan with features, eg. edges of pavement.

Set a grade

Check alignment

Determine how much channel work is required

Send prelim. design to hydraulics division with proposed waterway opening. Returns with changes, approval, required elevations, scour protection.

Pick a cross section

Select a class 3-R typical rural

4-R Interstate

Projects designed in-house are typically small rural bridges

Job is to make it fit functionally - very few architectural considerations

Ends with contract letting

**Consultant Design management:**

About 20% of bridge work is designed in-house, the rest (80%) is designed by consultants.

Typical INDOT engineer will manage 20-30 projects with ongoing work in design with continuing minimal involvement in about 10 more under construction.

Primary functions include:

Review of alignment set by consultant.

Accommodation for construction phasing

How will the design avoid closing the road.

Run around - how far? - large enough?

Has district been consulted for how traffic is to be maintained.

Evaluate cost comparison Based on INDOT unit cost data.

Includes no life cycle, or maintenance cost analysis.

Have lots of examples and pictures, but no numbers to use.

## Constructability items which should be included

Is there room for equipment to do the job?

How can the clear-zones for safety be effectively included?

There is not a list of what should go into preliminary plans. Identify what should

be included and why.

Make a list of milestones and requirements for each function.

System to explain why we do what we do, with an example plan with a checklist for each page; what sheets should be there and which shouldn't.

Windows of information showing the way things are actually constructed; what makes some details great and others a nightmare.

Video of regular operations, eg pile driving, forming embeds, piers and pouring bridge decks.

Could use some help selecting splice locations on steel beams; include beam flange width changes, and stiffener-web design tradeoffs.

Decision expert system for pile selection for bridges.

Front end program to weed out what doesn't fit the program and identify why not and what to do about it. eg superelevations etc.

Library of standard details with advantages, disadvantages; what to use and what to avoid with specific details. Circumstances for use and specific assumption used for details

Need to reduce pictures and examples of maintenance problems and life cycle information to quantifiable numbers for use in alternatives, value engineering analysis. Have historical storage of 10-40 years of repairs, type and cost.

Need expert system to reduce errors in the application of INDOT unit cost data to the investigation of alternatives.

Need expert system to evaluate changes is type, spacing, and # of girders to use for bridge design. Example 'T' style proposed last year saved $.75 Million on 1 job.

Desire a system to interface with design, providing good and bad options, for comparison, but not to do design.

System should gather and infuse the department with ideas from out of state.

System would be best if compatible to and from CAD.

**Summary of Interviews held Mar 22, 1993 with Road Work Design Division Chief and Construction Operations Support Division Chief at INDOT**

Interviewees -- INDOT

**John Nicholson** Road Work Design Division Chief
**Tim Bertram** Construction Operations Support Div. Chief

Host INDOT -- **Walter Land**

Interviewers -- Purdue

Dr. Bob McCullouch
Robert Patty

## Goals

Our intent during the interview with John was to extend unstructured interviewing began on March 10th to the Road Design area. We then proceeded into construction management to identify those areas felt to have the greatest potential to benefit from an intelligent hypermedia based system for constructability lessons learned.

## Results

The design process in the road division was found to be substantially similar to that of bridge design. (See March 10 notes.) Ten percent of road design is currently accomplished with in-house engineering and 90% by consultants. Designers are encouraged to call contractors, field engineers and other consultants to assure the inclusion/resolution of constructability issues.

**Suggestions for inclusion in the system:**

Maintenance considerations
Clear-zone definition -- needs expert & hypermedia systems
Guardrail/bridge termination options
Traffic control/maintenance
    Sequencing of construction & matching elevations
Memo revisions/revision of revisions
Utility problems -- needs both expert & hypermedia systems
    Drainage
    Unmovable utilities which the design requires moving
Bridge Piling -- expert system
Video clips of how standard things are built

Appendix B: Contractor, INDOT District, and Consultant Interviews

# Table of Contents

## Transcriptions of Two Contractor Interviews



## Listing of the Balance of Contractors, INDOT District Engineers, and Consultant Interviews

| Company | Individual | Position |
|---|---|---|
| Reith-Riley Construction Co. | Max A. Rowland, P.E. | Project Manager |
| | Larry A. DeWitt | Superintendent |
| | Richard Ballow | Superintendent |
| Contractors United, Inc. | Mark Thompson | Const. Engineer |
| | Ted Brunner | Vice-Pres. Bus. Dev. |
| | Terry L. Morgan | Vice-Pres. Bus. Mgmt |
| Schutt Lookabill Co., Inc. | Janet L. Schutt | President-Owner |
| Beaty Construction, Inc. | Leon Beaty | President-Owner |
| INDOT Districts | | |
| Crawfordsville | Frank Switzer | District Engineer |
| | Sam Castleberry | Project Manager |
| Janssen & Spaans Engineering | Leo Spaans, P.E. | Concrete Bridge Engr. |

**Interview held March 7, 1993**
**Held at J.S. Sweet Construction Company, Cambridge, Indiana**

**Experts**: **Jim Sweet**, J. S. Sweet Company - President
**Dan Sweet**, J. S. Sweet Company - Vice President

Experience includes road and metal building construction, but has primarily been a major general bridge contractor for INDOT. Jim Sweet is a graduate civil engineer from Purdue. and has 36 years of experience. Dan attended both Purdue and Ball State and has 15 years of experience.

**Interviewer**: Bob Patty

The Sweets were primed with the purpose of the study, and questioned to assure they had a correct understanding of what constructability means. They did, and proceeded to describe principles as follows:

# Environmental

Jim: Environmental protection measures have been applied by D & R which require the contractor to be out of the stream between April 1 and July 1st. This is accomplished with a blanket order which must be taken into account when the job is bid. There may actually be some latitude if there are no fish spawning in the area during that time period. The D & R people may come out and take a look at it, but I must figure that job as if I cannot be in that stream from April 1st to July 1st.

Jim: For example, in the last letting, there was a requirement for no clearing between May 1st and September 1st for protection of the Indiana Brown Bat. It was let in March, which meant that it would have been awarded in the middle of april which meant I had 2 weeks to do all the clearing. On top of that, we couldn't be in the stream from Ap 1st to July 1st. D&R doesn't have enough people to send out to examine each one of these job sites before they are bid. But they are paying for it indirectly because I have got to figure it in my bid. If they would get someone out there to investigate before the bid, like they do after. They could say, OK, there is no problem here because there is no nesting or fish spawning, so the contractor can get into the stream, and put that in the bid.

Q: Tell me more about the environment area. If I understand it, there are a number of different animals and fish on the endangered species list and the environmental impact statement done on the project identifies which have a problem?
A: The stream work restriction for April 1 to June 30 is a blanket for the whole state. Actually, depending on the species and temperature, fish are migrating through state streams from mid January through August and they tried to find a time span which

covered all species. And that is the April 1 to June 30 period. They are not reviewing our plans in terms of going out to look at the site to determine if there is an impact there that needs to be taken care of. They have 12 biologists covered up with D&R work, they don't have time to do INDOT work.

Q: So in effect you put the cost of doing it and then go back afterwards and try to get some relief.
A: Yes, exactly. And then they hit us with a wavier, that we didn't know about, to allow certain types of inchannel work to be done for specific time frames and specific activities. But you have to apply for them, and then they will come out and look at the site. Cost and time savings, if achieved, stay with us. If the state would do it initially, the savings would be theirs.

Q: What size problem is this?
A: That varies, but several thousand dollars to say the least. We have higher mobilization, overhead, and it results in higher wage negotiations with our labor unions because they are effectively locking us out of construction for 6 months of the year.

Dan: another example is the brown bat exclusion for not clearing from May 1st to Sept 1st. This is another blanket requirement, but if we call D & R, they ask if it is a relocation or on the same alignment. If it is on the same alignment, then bats won't be a problem. Bats won't come within 100 ft of a road. D&R asks us how far or large our right of way is. If we say 30 to 40 feet, well then they say the bats won't come within 100 ft. then, so why put the requirement in the special conditions?

Q: Is there any conditions or situations? If there is a stream in the project then the problem exists right?
A: Yes, even if there is no water in the stream. We've seen it on streams where the streams are dried up. We've seen it on streams so small, you can step across. And actually there was one that was a drainage ditch which had what looked like dishwater, nothing could live in it, but the requirement was still there.

Q: Are there other conditions for the bat? Is the requirement on every job for which any clearing is required?
A: Yes, But that seems to depend on who saw it at D&R. If the guy has a pet peeve for Brown Bats, then the requirement will be there.

Q: Do they see the job before the bid?
A: Design sends plans over to D&R and they are supposed to review the plans at that point. So if there is clearing, then the requirement goes in there.
Jim: The job in Henry County doesn't have the requirement. But it does have one for instream excavation below 9'3.5" which I don't understand.
Dan: Design starts talking to D&R 5-6 years before the job will be let, who never review it again until after it goes to bid. So what they came up with 5 years ago is

what is in the contract today.

Q: At the very least, D & R could come up with some kind of criteria, guidelines which could be given to design engineers in charge of the job, which would protect their interest if they don't have the time or resources to go through every plan themselves?
A: That seems reasonable, but to go back to D&R and get them to retract something is, we hear, a nightmare. They do have a review with them before the permit is issued where they will try to take exceptions. We were happy to get anything after going into that meeting, because before, we had nothing. Due to public desire to protect the environment, D&R carries a lot of weight, perhaps more than other departments.

## Special provisions

Jim: The special provisions today are not special provisions, they are blanket provisions that they are putting under the title of special provisions. They may or may not apply. For example, a project was put out for bid with the requirement for a 24 hr watchman. Why in the name of.... do they need a 24 hr watchman? We called the state and they said we don't have time to get out a retraction, so bid it 'accordingly'.

Do I put the watchman in, and then they are going to take it out, then they are going to come back and say, 'we want a credit because you're not going to need it, we want to take it out.' Or Do I leave it out, like everyone else will be, and say I will give you a token payment. If I put a night watchman in for a 5 month period, that is a pretty sizeable chunk of money. I'm going to loose the job, or the state's going to be paying more money than they need to. They need to look at their special provisions and make sure they apply.

## Utilities

Utilities are the bane of our existence. We have a job now that we bid the 16th of march. We'd like to start it. They say as soon as it is staked out, they will move the utilities, but they anticipate a 30 day delay in getting the utilities moved. The job was bid in March, it won't be awarded until the middle of April, it won't be till the middle of May before we can start, so we have really lost a good 2 months of construction. We don't have open winters, so if we get 8 or even 9 months out of a year, we are really pretty successful. If you loose 2 months on that...a little thought...

Another example; the power company had been given permission prior to the bid to relocate their lines. But the approved location did not appear on the bid documents. And when discovered, it conflicted with the required temporary traffic facilities as well as effectively closing off dozer and crane access to the project and

seriously confined the remaining working envelope due to the need to avoid the crane boom coming closer than 10-15 ft from high voltage wires.

Often, the centerline of the temporary road is given, but not the outside limits. They need to draw the whole temporary road where it is going to be; the shoulders, toe, the whole 9-yards, to see how it infringes on other temporary structures and permanent construction processes. The locations of these 3 utility poles were not shown on the plans, ever. It wasn't until the utility company was out on the job setting the poles, that we said you've got a problem with this.

This happens frequently with utilities, all the time. Poles are not where they say they are. Our crane with crawlers is 12.5 ft wide. They were putting the poles in allowing only 10 ft for temporary passage. Further, they didn't leave enough room to get under the powerlines with the crane. The result of these extraneous utility plan changed the whole modus operandi of the job. The contractor was not brought into the picture with the utilities until they were already on the jobsite setting poles.

Q: When are arrangements typically made with the utility companies?
A: Before the letting of the Job.

Q: They have the information available and could show it on the plans?
A: Yes, but you have to consider not just the location of the poles, but also a 4-8 ft cross arm and wires on the poles which are only 20' high when you have 80 ft of boom in the crane.

Q: To avoid a high voltage power jump, is 10 feet really a safe distance from a powerline?
A: It is safer for the crane operator sitting in the cab because he is insulated from the ground, than it is for someone grounded, standing on the ground grabbing a concrete bucket or lifted load. We like to keep at least 15-20 feet if we can.

Dan: Leave the planning of the utilities down here in the district. We get into trouble, the utility companies tell us, when the question goes from their downtown office over to the INDOT office downtown. If they get the district utility guy and the contractor out to the job, they get it resolved. (Interviewer comment; this will solve the problem once it has happened, but it will not prevent it from happening in the first place. We should find other feasible alternatives for prevention).

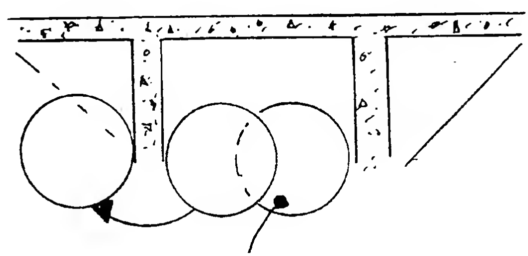
## Right of Way constructions

On Highway 67 north of Pendalton, the temporary bridge is so close to the structure that the toe of slope on the temporary dirt runs back underneath the new structure. Now that means, if we build the job according to the plans, we would have

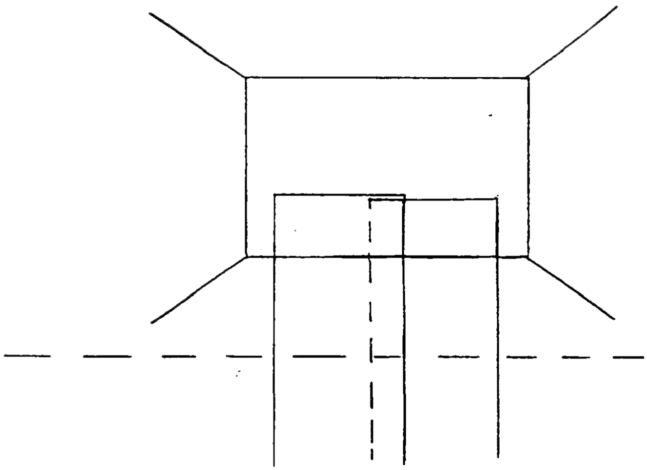
to sheet and shore the temporary fill to put in our encasements, which is kind of ridiculous. If they could get a little more right of way, and move it out... We have gone to the state and said we think we can get a right of entry off these property owners and we are moving the temporary over on our own, just to clear. Dan mentioned the problem, and the engineer said, I never gave that a thought. It is so close that we will have to provide a temporary barrier to prevent the splattered concrete from the removal of the existing bridge from falling on the cars. It is that close. On the other side, which is our only access, downtown Indianapolis approved moving some power lines that has effectively blocked us out. We have no way of getting a piece of equipment in there.

Examples:

3 Span Slab

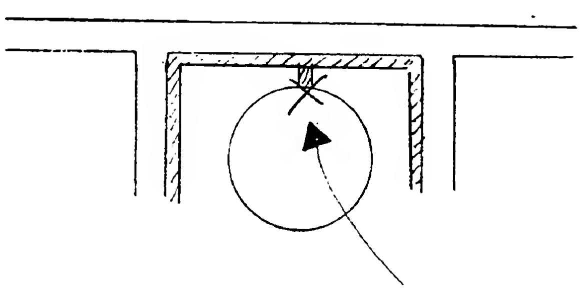


Pipes, to use for the temporary road, go under the new bridge, and are in conflict with each other, and with shoring required to form and pour the slab.



Center line of temporary
road

Why do they put the temporary road so close that the temporary drainage pipe goes underneath the new bridge? This increases the cost.



Shoring supports are required to form and pour the slab.

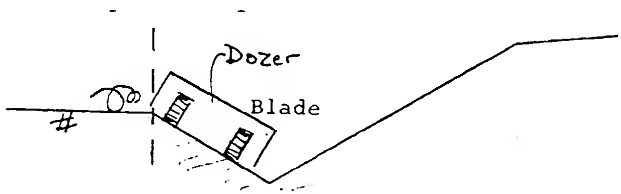
A little more right of way, moving the temporary bridge out, would leave that in the clear. There is no way to get the bridge built, that I can see, not the way we do it.

Jim: If I've got a tight situation to work in, it is going to cost me more money. I'm either going to have to go rent some ground off of somebody to work, or I have to work at a very big disadvantage. ie,. the utility lines on the one side of the structure, we have to work with a low boom, not very effective to get under the lines all the time.

Under additional questioning from the interviewer, Jim shared the following:

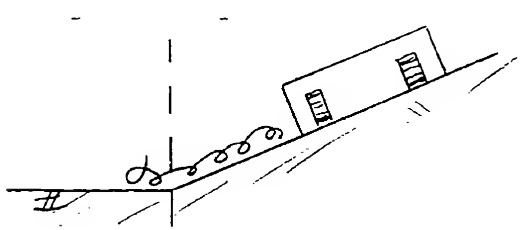
Right of way limits are normally the same or close to the construction limits. If you are cutting a slope or a ditch, you cannot possibly have your construction limits identical to your right of way limits and get the job done.

Construction Limit
& Right of way




This condition means that you are either going to have one track up here on top when you start out, or you're going to have to have the spoil come up there and then you can gradually work it back.

Construction Limit
& Right of way



The same thing will happen on a fill. If I have to fill coming down here, and this is my right of way, how do I dress the slope? You can lay the material in, but it is still going to spill down the slope. And at the end of the job, you have to dress it and push it back up. With the Right of Way at the toe of the slope, you haven't got any room to work.

Q: How much is needed?

A: Jim and Dan:

10 feet minimum.

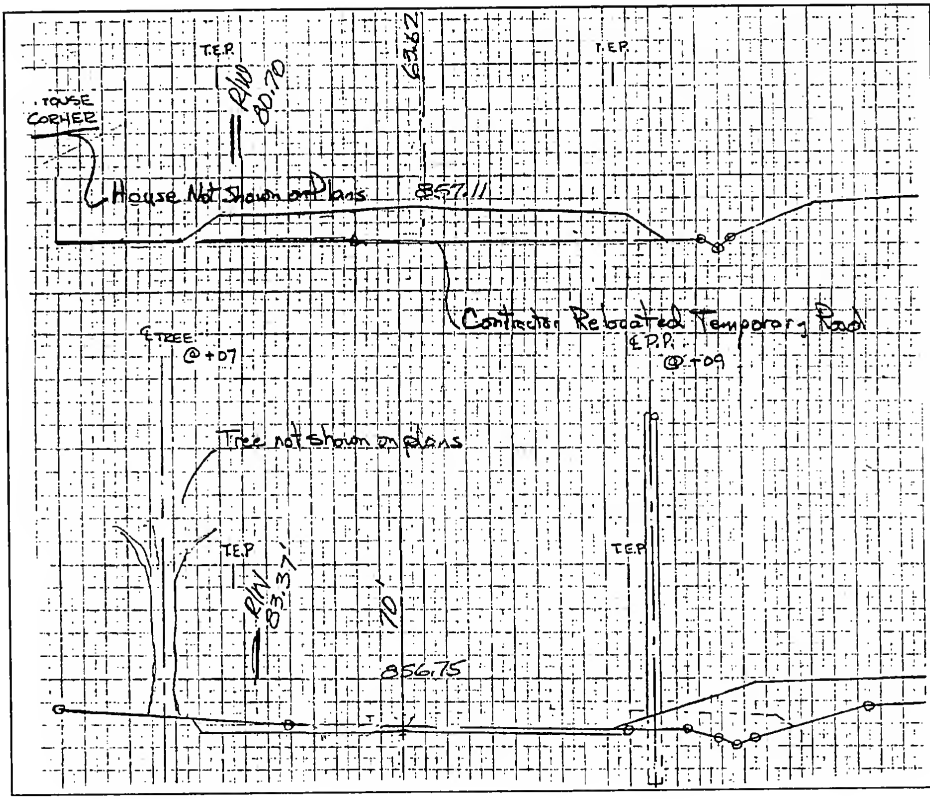
Some examples on project BRZ-9933 are shown with the ROW only 2-5 feet from the limits of this type of construction. On the 86th street project, in several places, the ROW is the same as the construction.

Q: What do you do in these situations?
A: You have to make some sort of deal with the property owner, and we are going to pay more then if that state bought the right of way. Interviewer note: ( The state's right of eminent domain allows them to purchase rights of way at market prices. Once awarded the contract, the contractor will pay anything up to the marginal cost of alternative means of constricted construction, in order to obtain increased limits. This marginal cost may far exceed the market value of the additional property.)
Dan: In Pendalton, we have already made the deal with the property owner, but they are going to be a real pain to work with for the rest of the job.

Under questioning, the experts revealed that sometimes this cost is added as a line item on the bid. Sometimes the problem is not found until after the bid and becomes an additional cost to the contractor.

Q: How would a reviewer or designer identify where potential problems of this nature exist? Doesn't it depend on the slope, or what is being done in order to determine how close the ROW can be to the Construction Limits?

A: The right of Way should be shown on the cross sections with both the temporary road and the new facilities. Then one can see if they have a problem, for example:

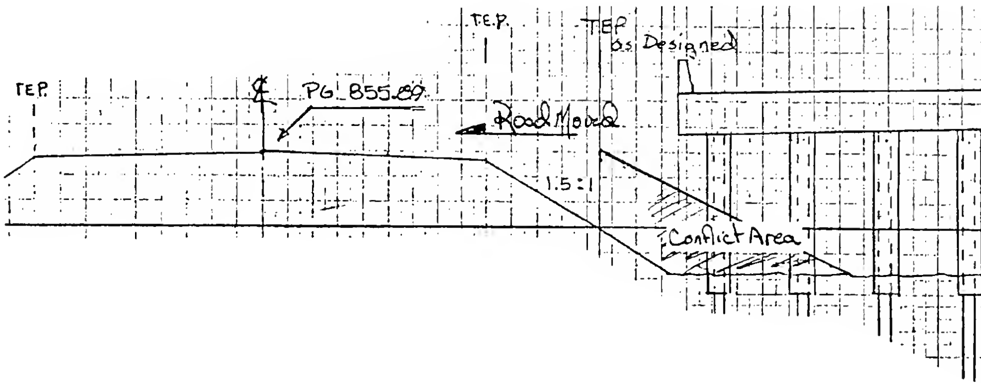



Drawing A

The original design for the temporary road put the embankment of that road in conflict with the encasements of the new bridge. This would require shoring and reexcavating the embankment of temporary road after constructing it in order to put in the encasements for the new bridge. A redesign of the temporary was required by the contractor.

Q: Referring to contractor's drawing B, Were any sections like this shown on the design?
A: No. There were no sections through the bridge. Sections were made on the approaches up to the end of the old bridge, but not on the bridge its self. In addition,

it is often found that contours, and obstacles (trees, homes, utilities, etc) beyond the constricted ROW are incorrect and incomplete, rendering redesign by the contractor very difficult and expensive, especially during the heat of a bid. See Drawing B below.

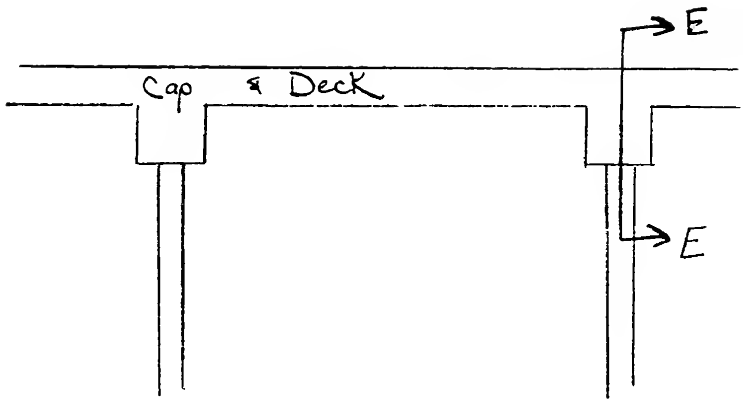


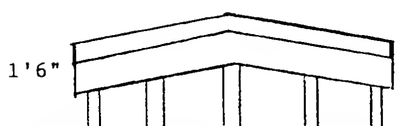

Drawing B.

Q: Tell me a little more about the trafficking problem besides the right of way.
A: There should be at least 10 ft beyond the construction limits for utilities as well as us or they have to make a deal with the property owner. We were told verbally and in writing that there was a gas line on a job, but that it was completely out of the way and would not cause any conflict. The first hour on the job, our cat operator fell into a hole by the gas line and ruptured the 8 inch gas line. A man could have been killed and it cost our insurance company $10,000 to avoid a court battle. So, we now take the attitude that we want the utilities moved completely out of our road.

## Column Cap bottom slope

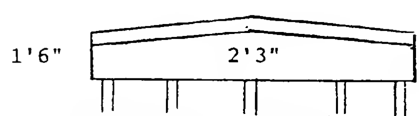
We run into this all the time, On an integral cap slab bridge where the cap is poured with the bridge itself, (with the deck), some designers will design the cap bottom to follow the same slope as the deck.




Bottom cap sloped to match upper slab

A Good Detail E-E




Bottom of cap level creates difficulty in forming and adds dead load

A Bad Detail E-E

Slab Integral Cap with good and bad details of straight bottom

Also see Drawing 913-2 J.S. Sweet Construction Co.

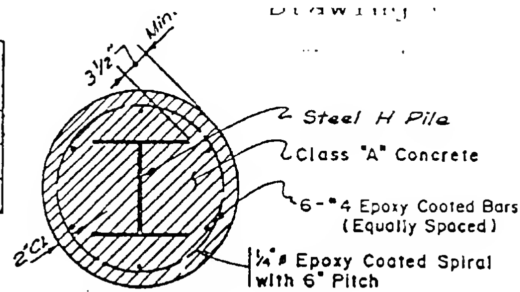
Conflict occurs where sloped slab form framing meets a level support at the cap. Sloping the cap bottom with the slab eliminates that conflict.

# Other bridge forming problems

One cannot form the back side of shear walls without the use of thick and costly layers of styrofoam which would be left in the void.

Round forms are cheaper for encasing piles than square forms.
One needs to dimension required clearances to enable the use of 20,22,24,28,or 30 inch diameter forms which are available. See Detail C.

| | Reinf. Steel /ft. length | Class "A" Conc. /ft. length |
|---|---|---|
| HP 12x53 | 5.8 lbs. | 0.12 cys. |
| HP 10x42 | 5.6 lbs. | 0.10 cys. |
| HP 8x36 | 5.4 lbs. | 0.08cys. |




REINFORCED CONCRETE ENCASED H-PILE DETAIL

Detail C Encasements of epoxy coated piling

The designer has a tendency to put too much extraneous information on the plan view of the drawing. He has all his curve data, ROW structures, Traffic Control, phasing, etc. He should have 1 drawing for utilities, 1 for topographics, etc.

There is a general lack of overall dimensions which are useful for layout. This is especially annoying when the dimension needed is on some skew. CAD drawings generally do not show sufficient dimensions to build the project. The computer obviously has the dimensions internally, but does not print out enough of them to build the project. eg. Bridge Bents.

It would also save a lot of money if standards could be developed and adhered to for piers, caps, bridges, slab thicknesses.

## High density area steel erection

A problem which design engineers should understand and appreciate, but for which they often have little on no experience.

## Conflict when replacing existing structures

The necessity of relocating 2 bridges was experienced because the new bridge pile bents would have gone right on top of existing bents. An accurate layout of where a new bridge is going to interface with the old bridge foundations and abutments is not typically given on the plans. So knowing how much of the removal of the massive concrete of the existing bridge and requirements of backfill (expensive B-fill), is not possible. This increases contingencies and changes.

Q: Would overlaying surveyed locations of the old structure with the new bridge eliminate the expense of conflicts.
A: yes, and to be honest, bidding is so tight, we usually take it in the shorts when a problem like this surfaces unless they will let us move the bridge, after the fact, to eliminate the conflict.

**Interview held March 9, 1993**
**Held at Fauber Construction Company, Lafayette, Indiana**

**Expert**: **Jim Gross**, General Manager, Business Development
Fauber Construction Company

Experience includes road, asphalt and other commercial and industrial construction, but has primarily been a major general road contractor for INDOT. Jim Gross is a graduate civil engineer from Purdue Construction engineering and management department. and has 15 years of experience.

**Interviewer**: Bob Patty

Jim was primed with the purpose of the study, and questioned to assure he had a correct understanding of what constructability means. He did, and proceeded to describe principles as follows:

# 10 years ago

A lot of times in field check procedures, they haven't looked very well to compare their plans with actual field conditions. We have been told various reasons. Sometimes a designer comes out and looks at the job and goes back and designs it and never comes back to compare the design with field conditions. We have had jobs that have been put out for bid that have items missing, there are work items shown in the plans and there are no pay items set up to do that work. We have a simple resurface job now in the crawfordsville area where we had curb removed, but no pay item to put the curb back. It seems like something like that is very basic. If someone would look through the proposal, they can see that curb is being removed, but there is not any pay item to put any curb back.

Q Can you give me a couple more examples?

A We are working on a couple of projects right now designed by outside consultants 8-10 years ago, and they have been on the shelf. They have pulled them off the shelf and put a new proposal book together and been put out for bid. Items are in there which have changed. The specs have changed, there are items in there which the state no longer does that way. The project has changed because there has been other work done in that area during the 8-10 year period. That totally changes the scope of work; so you have this set of plans which really aren't very well related to the area at this time.

Q How do you suppose a designer could ascertain that this problem existed? A simple come out on-the-job site and compare what is existing with the plan.

A Yes, something closer from when projects was designed. I realize that due to budgeting, something can sit up on the shelf for quite a while before actually being approved for budget. But sometime before they go out to bid, they need to be reviewed by looking through the contract items and a site visit to make sure that these things make sense; probably by someone with some construction knowledge. There have been changes, buildings added in this area that don't show up on the plans. How are we going to get people in and out of the building when the road is torn up? There is no driveway here according to the plans. That creates a problem between the state inspector and the contractor because they were not addressed in design, and now they have to try and solve them out here in the field. (Gross 1993)

## 2 Projects put together

Another thing that has happened, on a job that we have right now; two projects were put together under one contract that was designed by two different designers and consultants and they were never put together before the bid. There is overlap in bid items. The alignment is different from one job to the other, ..where they come together. They had different specifications and different cross sections, the jobs are almost unrelated. They just happen to butt up next to each other. One was designed some years back and they decided to put them together, and nobody looked at the consequences. When they were put together, there was no traffic control plan, they were designed completely independent and they could not be worked that way. (Gross 1993)

## Cost of building a road half at a time

Q Can you give me a few more traffic control problems?

A I would say traffic control is one of the bigger issues that design people have a problem understanding if they don't have any field experience.

Q Can you give me some examples?

A The room needed to make things work. The cost of building a road half at a time vs closing the road and having the entire area to work in... I don't think that has been explored very well. Possibly doing a detour or building a temporary road or runaround so that you have the entire width of the road to

work in, rather than trying to build grade, put in pipe and pave in lane widths. I'm not so sure that it wouldn't be cheeper to build a runaround. You will get a much higher quality project if you can build it in larger segments than some of the smaller pieces, the way some of the jobs have been designed. Safety would be an issue at that point as well. If you can isolate the work area from the public, it is safer for both the workers and the public. A detour does add some miles, but considering time to get through a project and safety, that ought to be looked at more.

Q Let me explore this more, the idea of breaking down a project, rather than putting an alternate route through. From a design stand point, it is obviously less material, it is back to that engineering problem of minimizing material as if that would miraculously minimize cost. Can you give any rules of thumb so that looking at a set of plans you could discern that: 'this guy is off base, he is stepping over dollars to save dimes, if you will?

A When you cut paving, utility, or earthwork operations down into pieces, where you can't even get a full day's work in a work area out of that kind of a crew, you tremendously impact the price of those work items.

Q Can you give me some rough -- lets get a little more specific here, say were doing things in a 10 or 12 ft. width. Is that a pretty standard construction width that they pare you down to?

A Gesture in the affirmative.

Q What is the relative cost of going through and building a road in that fashion with all the utilities and every thing else that is involved, rather than the cost of adding the road around the site? Can you give me any way to evaluate that?

A One simple way would be to look at the difference between the mainline paving costs vs approach paving. Approach paving is that piecemeal type of paving operation. If the State looks at their unit price book, they will see that they pay \$35-\$50/ton for paving for that type of work. That would be cut up, messy type paving. If they look at mainline paving, they get that kind of work done for maybe \$20-\$30/ton, low to mid 20s. So you are anywhere from doubling to tripling the cost per unit when you cut it up that much.

Q So that would have to be off-set then, by the cost of the additional work on the by-pass. But again, if you are double, or triple the cost, you can do a temporary by-pass.

A Yes, and that is just on the paving operation. The utility and earthwork operations would have similar type of inefficiencies. It would be very easy to

say that you are going to double or triple your labor and equipment in those items when you really cut them up and fragment them into smaller work areas.

Q Let's kind of expand this concept a bit and go from a 10-12 ft. width, to say a 20 ft. width. How much does that reduce your cost? When do we begin to tail-off to where we are going to be roughly in the mainline area?

A I would say when you get into the 20-24 ft. widths, the biggest thing at that point in time is that your construction equipment can pass each other. Otherwise, you have a real traffic flow problem and you don't have a wide enough area to get equipment around in front and behind your operation.

Q And that is the deciding factor; can you pass the equipment?

A Yes, that is one of the major factors.

Q What are some other major factors that a designer could look at and say they were creating this problem?

A And then just the lengths of the areas that you have to work in. Say you are working on an urban project, and you are going to limit the areas to 1000-2000 foot long work zones. Then, you've done the same thing that you've done with the widths. You've made an operation where you have limited the contractor to be very inefficient.

Q That would be in these small messy approach areas?

A Right

Q When would you be in the mainline?

A When you get over half-mile to a mile, then they can become efficient. (Gross 1993)

## Cross-overs on 4-lane roads

Q Tell me a little more about trafficking problems. What errors or problems do you see coming down the pipeline?

A The State has become a lot more cognizant of that and the contractors have also, as far as traffic control problems. Where they have built cross-overs on 4-lane roads and given contractors the entire one side of the road to work on, it has made it a lot safer for the contractors and it really hasn't impacted the

traveling public that much because if they are going to be traveling through that work zone, they are going to be down to one lane anyway.

So instead of one lane on the construction side, it has made it one lane, three each way, both on one side of the road. It has made it a much safer area to work. Most of the accidents occur in the funneling area, where you take it down from two lanes to one lane. Once you get them down to one lane, you really don't have a problem, they don't have anyplace else to go and they move along. The traffic jams and tie-ups occur at the narrowing down point, at the merging areas. Then you've gotten beyond the problem, and it has allowed the contractor to be a lot more efficient because they have an entire side of the road to work in and they don't have to worry about traffic at that point.

One thing that the State has done that I think is incorrect, is that they have limited those work zones to 2 or 3 miles. Once you get traffic down to one lane, the length of the set-up, whether that is 3 miles or 10 miles, really is immaterial.

Q It is the necking down that is the problem, and everything else flows anyway.

A Right, and so what they have done if they say you have to do it in three mile lengths, they have added the expense of the additional cross-overs. They have added the cost of phasing. It adds money to build this section complete and then move to the next section, and build it complete. If you can build the entire side, there would be a significant savings.

That is a fallacy to think if we limit the contractor to 2-3 miles were going to move traffic quicker through there. I don't think that after you get the traffic down to one lane that it makes any difference in time that it takes to move through the work area or very little difference.

Q Is there anything else - do you build bridges?

A We get involved with bridge work as an earth working or paving subcontractor, but we don't build the actual structure. Utility grading paving.

Q Let me back track, since I've been able to pull that type of intelligence out of you. Let's go back to this concept where you suggested that instead of doing crossovers on a 4 lane highway, once every 3 miles, say you are doing a 20 mile stretch. If you don't have to do a cross over every three miles...How much does a cross over cost?

A About $50,000.

Q How much additional costs are involved?

A I would say another 2-3% of the project would be the inefficiencies, so if you were looking at a 10 mile reconstruction of a 4 lane road, you would be say 6 million dollars, it would be 2-3% of that. Deleted 4-5 crossovers at $40-50,000 each. So you could cut several hundred thousand dollars out of that project.

Q Are these crossovers ever left in?

A No, we always take them out.

Q So, the $40-50,000 includes the cost to take them out?

A Yes, $4-5,000 is included to remove them.

Q Why are they removed?

A Because they don't want the public using them to cross over.

Q They couldn't effectively put up a fence and leave them there?

A That has been done in the past, but people take the fence down, or it falls down, and then the crossover occurs; so typically they are torn out.

Q It seems that you could put something permanent that wouldn't come down?

A You could put a earth berm 3 foot high and seeded, or something like that and save $3 to 4,000. (Gross 1993)

## Utilities

Q Tell me about utilities, others have mentioned problems in that area.

A Yes, it has been a problem with utility work when other utilities have not been shown properly on the plans. Then you run into problems because you run into utilities and don't have room to put in the new construction. And it is difficult to get those kinds of decisions when you have an excavator and a crew and crowds of people sitting there trying to decide what to do or how to relocate this utility when you are working. So a better job of locating and showing the existing utilities on the plans would really help.

Q When you eventually work out the problems, you've got somebody from the utility district, a field person that can physically locate where those utilities are. The idea of course would be to do it up-front before you have to get all of those

professionals out into the field to resolve the problem. How would you suggest that it be practical for them to do that?

A I think that a lot of times plans are put together by getting the utility plans in from the utility companies and showing them on their drawings and nobody has looked at the depths. It will be just the utility company saying they are normally 30 in. or a 40 in. bury or something like that. Nobody has gone out and physically looked at the field in that area and decided that, that really makes sense. You've got gas and water and telephone. If they all say that they are in this area and that they are 40 inches deep, well that is not in reality what has probably happened. So if they could have the utilities do their locations out on the ground prior to final drawings, then we'd catch more of these problems. Plus, I'm not sure but what in critical areas, if they would do some exploratory type of digging.

Q To hire a contractor with a backhoe?

A Yes, it would be a lot cheaper to do it at that point than to go through the change orders and the hassles when you're out there actually trying to build it.

Q Again, the timing may be a critical factor if they are doing the design and then shelving it for - 10 years, are they really waiting that long?

A Yes, there is a bridge project outside of Dayton which was designed in 1978 and we are just working on that project now.

Q No kidding, that will almost necessitate a redesign. Even the codes have changed.

A Yes, we have had two spec-book changes since then.

Another serious problem with utilities has been public utilities being in the way, and getting them to relocate prior to construction. Every single reconstruction project that we have done in the past few years, we have had serious delays due to waiting on utilities to relocate before we can go to work.

Q Can you give me a scenario, build one of these things, what happens?

A OK, we have a preconstruction meeting and we have the utility people come in because we know we have to have utilities relocate work done before we can do any work. They come in and say they have never been notified of the project and don't know anything about it. We've got a job and a signed contract and we're supposed to begin work in two weeks and the utility companies don't have any of their materials and haven't planned to do any of this work

relocation because they claim they don't know anything about it. I think sometimes they do, but they aren't going to go to the expense until the contract has been awarded, and they know it is going to be constructed. I assume that sometime in the past, they have gone ahead and done their relocations and the job has never been built. So there needs to be some commitment done ahead of time.

We had a job last year which was delayed three months waiting for a telephone line cable to relocate. We couldn't put the storm sewer in because it went where the telephone line was currently and we couldn't do any work until the storm sewer was in. That has become a major problem, that at the beginning of each job, you need to allow 2-3 months for the utilities to relocate and get out of your way before you can start work. And the time of the year that they are bid and the timing that the State puts on those jobs as far as the amount of time that you are allowed to work, can be greatly impacted, and have been on almost every project; by utilities.

Q Let me explore this a little deeper. I may have to go back to the State to find what the appropriate time, or mechanism would be in order to get this done. But let me explore your understanding, so that I can get the most I can get out of that. Sometimes they don't build jobs that they have designed. But at some point during the process it becomes a go project. Do you bid projects, actually open the bids and then have the contract get cancelled?

A That is rare, but if it is over the budget, it may rebid. But we also had a job last year that happened to be in conflict with a detour of a job that was going on at the same time. It was cancelled to avoid closing all the roads in the area. But, I also have been told that project will come up again this year. So if the utilities had gone ahead and relocated, they would have been a year early, but it would not have been wasted.

We get a three month advance notice on what projects are coming up. I think once they get into the pipeline that much, they are going to happen. There could be some monthly delays, but I don't think that the funding is actually pulled away from those jobs and cancelled, once they get that far in the pipeline. The State knows three or four months in advance whether these reconstruction projects are going to come up this season or not. At that point in time, if they could get the utilities to relocate, they have avoided huge problems.

The other thing that the utilities want before they are going to do anything, is for somebody to go out and stake where the new right-of-way is going to be. The State should do that at the time. They need to do that anyway because if they are purchasing a new right-of-way from the property owners, that tells the property owners where their new property line is, and lets everyone know where

that is at. Then if they stake it the utilities can go in and start their relocation process.

Q Sometimes, in discussion with other contractors, we find that the way the State has designed it, for example, the temporary road in conjunction with the existing system the utility movement shown on the plans isn't actually what ends up being the case. Is that true in your road work? Have you had to have them go a different place then originally designed?

A Yes, because it wouldn't fit in with the actual work on the plans, and the utility relocations were not really coordinated with the new work.

Q So, in the best of all possible worlds, that would not occur, but in fact, it does occur; so it may be that in-as-much as they are not being compensated for it until they raise their rates to their customers or something. So maybe it would be wise to wait until you have the contractor in hand before they actually come out and start to put the utilities in. But on the other hand, could they preorder the material with a very large degree of safety and have the materials standing by so that when it is finally approved and you agree, and the State agrees, that this is where it is going to go, they've got the materials and organized their crews to the point that they can get out there and get the job done.

A So that they are ready to go to work. Yes, if at least they were at that point, it would be a big help.

Q Could you conceive of any condition or circumstances that maybe someone would create that would provide a better overall solution to the problem?

A Yes, I think that a preliminary meeting between the State and the utility companies prior to a job being awarded or bid, to get some of this stuff staked ahead of time would be a big help.

Q At least they can order their material.

A Yes, there may be sometimes when they are not going to be impacted. They are moving out to the right-of-way line and the construction activity is not going to impact by them at all. They could go ahead and get their work done.

Q Ok, I wonder if there wouldn't be some... I mean, if we're going to tell them to preorder before the actual final analysis is done, i.e., we have a contractor that agrees that this is what I need, and he becomes a real live part of the deal. It seems that the State would probably have to absorb some risk. That if they tell them to buy the materials and then don't eventually use them on this project or on another project, they would be liable for large volumes of materials that they

had preordered. But usually you could find some other place to use them in one area or another. But it may never come into play. And so they may be able to accept that kind of risk in order... How much cost savings is involved here, if after the preconstruction conference, in the next day or two could really have the utility guy out doing his work, and he's ahead of you. By that time you've had a few days to get your bonding in place, and to get your schedules worked up and so forth, so, you're really prepared to tell him what your modus operandi is, and can give him an area to start and so forth. If you could have that criteria, how much would that save you?

A It can save the contractor 3-4 months of job overhead. It is going to save the State 3-4 months of job overhead.

Q How much is that for your operation?

A On a large project, $15-20,000. / month job overhead. I assume the state would be similar type numbers because as far as job overhead, they end up with similar numbers of people and sometimes more people than we do, plus that much less inconvenience to the public. Because, once the sighs are up and there is construction activity on the project, you are delaying the public the full use of that facility, for that many months. , And that would also be impacted by the volume of traffic. So you can be talking some pretty sizable dollars.

Q Let me take this from a maximum to a typical, if you will. You mentioned that 3-4 months may have been involved in kind of a worst case scenario. What would be a typical, day in and day out, year in and year out; you get a project and you wait? Is it a month, 2 months?

A. Somewhere between 1 & 2 months has been typical.

Q. OK, so you are looking at, at least a $20-30,000 per job savings for that concept alone?

A Yes. (Gross 1993)

## Unqualified people doing the inspections

Q Anything else?

A One of the problems.. the state doesn't seem to have as qualified people doing the inspections anymore. Back when they were building the interstates, the inspectors had a lot of hands on experience with staking and seeing the construction, understanding the construction, and had a little more common

sense about the projects. They take young engineers right out of school and make them project supervisors and project inspectors. And they really don't have much feel for construction work. They have their specification book to go by but, don't have a good grasp of what is going on.

Q Separating what is important from what isn't important?

A Yes, and so you end up costing contractors a lot of money educating these people in actual construction practices, and in what is really acceptable and what is not. And spend time to help them read the spec book and understand it. And when they get very good at it they move on to working for contractors and other businesses and consulting. So, the state hasn't done a very good job of training people and keeping trained people out in the inspection field. It is very rare to go out on a project anymore and find really trained, qualified people inspecting the work.

Q Let me explore this more, because this stems back to the academic environment. We send engineers out of our civil engineering and structural departments with very little construction understanding. They can design, but they don't understand how, what they have designed actually gets implemented in the field. Can you elaborate on specific things that you end up training them for, things that perhaps we could take a video clip of the actual physical operation that is going on and teach?

A How things are built, what equipment is available and how things are really done. The other concept is that while they are out there taking a compaction test over an area, that the contractor, his people, and equipment are sitting there waiting on him to make a decision, or OK that test. And they don't realize how many dollars are just sitting there idle waiting for them to make a decision. They don't understand what kind of an impact they can have on work and what kind of an impact they will have on future work because the cost of doing business is going up because we're waiting on decisions and approvals. They need to really be educated that the timeliness of their work has a big impact on the cost to do business.

Q Let me explore this a little more. Name a few pieces of equipment that are generally waiting while an inspection is taking place.

A If they're proof rolling-- a roller, loaded truck, and operator and a superintendent. Total @ $100.00 / hr.

Q How long does it take?

A If for a work area, it takes them 1/2 hr for each lift, then you're building some

expense in

Q Is there any way you can conceive of that being done in a continuous or process mode, rather than a batch mode?

A If that is allowed, and you have enough area to do that, then that is fine. On new construction, that is not as big a problem as on reconstruction, where you're limited in an area. That is one of the cost increases associated with phasing. When you have phased something and limited these work areas. There is one thing that impacts it tremendously is just approvals.

Q When you bid a job, and are working in the environment that you've been working in, knowing that you are going to have inexperienced people on the job, impacting you at $100./hr, that maybe if they really understood, you wouldn't have to have a superintendent or other high level person out there to explain: 'No! you're really not trying to rip the state off', that this is a standard procedure; really bringing them up to par. Something that if we had a constructability program available that we could train this guy, would you be willing to coordinate with us and let us on your job sites to take pictures and ask questions, so that we can record these things to...

A Yes, sure

Q How much, or what % of a job is that really costing you? Do you have any feel for that?

A Not really, the only thing that you could possibly go by is that sometimes you have a job that doesn't go very well and one thing that you blame it on is that you couldn't get anything done, because you were trying to work with and train these inspectors.

I would be kidding someone to say that people build that into their bids. It gets built in over a long period of time because of efficiencies and inefficiencies. But, I would venture to say it could be up to a 4 to 5% of the total cost of the project. If everything had clicked and people had really understood what was going on and how to do things.

Q That is really the effect that inexperience has from the INDOT people onto your organization.

A Yes.

Q So, when you do your historical unit costs, that is where that number gets bid in, is in higher unit costs?

A Yes, I graduated from Purdue Construction management department and I think one of the big benefits of that, are the summer internships which are required to be served in the business. I think an internship or on-the-job training either before or after they graduate, to get some field experience, is a very good thing, and well spent.

Q That is a difficult thing to do. People get so busy that they come out here or there, but it quickly seems to fall by the wayside.

A Our company has decided it is worth the expense of doing that with our new engineers to give them field experience before they are turned loose into job management or estimating. (Gross 1993)

Appendix C: Lessons Learned

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## Foundations

### Use of Cofferdam Bottom Seal

**Guideline:** If extending an existing bridge, the designer should check existing bridge foundations to determine if seals were used. If seals were used, specifying them again, or consideration of a foundation type not requiring cofferdams such as drilled and cased or piers should be considered.

Qualifiers: 1.
Exceptions: 1.

**Benefits:** This is a safety issue, and alternatives should be considered.
**Reasons:** The use of a concrete seal at the bottom of a coffer dam avoids bottom blowout. The workmen's lives can be lost if this rather sudden quick-condition occurs when they are in the hole. It is caused by a combination of high hydraulic head and susceptible soils. A seal is costly, and the engineer can often consult old field records to see if the existing bridge foundations required them during construction.

**Source:** Weddle Bros. Construction

**Examples:**

**Graphics:**

### Deep Foundation Alternatives

**Guideline:** Alternatives to conventionally formed deep foundations should be considered.

Qualifiers:
1. Consider using alternatives when footings are very deep;
2. When excavations to form the foundations require adjacent streets and roads to be protected, or;
3. Under poor soil conditions and high water table, such that a quick condition may develop, and bottom seals will be necessary.

Exceptions: 1.

**Benefits:** Substantial cost reduction and time saving.

**Reasons:** Formed deep foundations require sheet pile coffer-dams to access the form. The coffer dam is at least a $50,000. item and may run 70-$100,000 depending on the size, required depth and/or bottom seal. Consider alternatives of driven precast piers or drilled (temporarily cased) and cast in place piers.

**Examples:**

**Graphics: 2:07 - Start video of extending pile cap and removing sheet piling at pier wall.**

### Accurate Pile Lengths

**Guideline:** Specify pile lengths based on blow counts, old pile driving logs and informal discussions with area engineers and local knowledgeable residents, in addition to the wave equation.

Qualifiers: 1. Apply this concept when using H-Piles or Shell piles.

Exceptions: 1. Note: more research is required to establish the utility of and quantify this rule of thumb.

**Benefits:** Lowers total cost for piling due to reduced over and under estimates for the required length of driven poles, and improves competitive bidding.

**Reasons:** Inaccurate pile length estimates are very costly because the contractor can only order the estimated lengths prior to driving the piles. Current practice provides an estimated minimum tip elevation, but they should be designing on an estimated pile length. We seem to always overrun the pile length by 10-12 ft. (Switzer & Huckleberry 1983)

If the estimated length is too short, the equipment must wait, @$80-$160 / hr or remobilize @$1500-$3000. to allow additional material to be procured. In addition, the final or upper 20 ft usually must be epoxy coated. If the design end bearing condition is not achieved with the procured epoxy coated top pile, another must be procured at a cost of more wait time and about $10-15. per foot.

If the piles are estimated too long, more material will be procured than required, with reshipping and restocking charges deducted from any balance. The epoxy coated top section may not be welded to the top of the pile and hence its protection would not be afforded that pile in the corrosion zone. Also, a wise contractor that can accurately estimate a significantly shorter length than the units in the line item estimates, can and routinely do (illegally, but successfully) unbalance the bid in their benefit to get the job by listing very low values for items they believe will not be supplied, which lowers their net bid. Removing the potential for windfalls like this reduces uncertainty and promotes better overall competitive bidding.

**Examples:** Tom Sweet of J.S Sweet Co. Inc., Contractors has found that a blow count of 50 will product a 40-ton bearing end condition for H-piles commonly used for INDOT bridges. For shell piles, the 40-ton requirement is typically achieved at a location in the soil profile with a standard blow count of 40.

**Graphics:**

Results of additional research in this area
Picture of a pile driving rig.
Picture of an epoxy coated pile welded on for the "last" upper section.
Picture of an epoxy coated pile being buried (wasted) because the 40-ton bearing condition was not achieved.
Video clip of the pile driving operation.

## Consider Economical Foundation Types

**Guideline:** Substructure limitations need to be considered when selecting a foundation type. Rather than designing foundations which require the contractor to build sheet pile earth retaining cofferdams, the designer should consider precast piles, or another type of foundation.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Reduced cost and time for foundation construction as well as increased safety.

**Reasons:** Subsurface investigations are at times inadequate, and at other times poorly utilized in selecting among subsurface options. We don't use drilled caissons in Indiana. That is a good option for penetrating below unstable materials especially when they are below the water table. The wave equations is helping, but we are just scratching the surface on technology available. FHWA requires that we do the boring, but we often not selecting the most economical option. We need to train our engineers on the available options and when to use them. Tom Davidson of University of Illinois is very authoritative in this area.

**Examples:** For example, on a project, the subsurface investigation showed blow counts of 3-4, a very unstable material for 10 to 12 feet below the bottom of some footings. The only way to excavate that material and replace it with engineered fill was to put in cofferdams at about 40 to $50,000. each. Rather than requiring the contractor to build sheet pile earth retaining cofferdams, the designer should have considered precast piles, or another type of foundation. (Leon Beaty)

We had 35 ft piling set up on a project and could drive them only 15 feet. On another project, we had 15 ft piling set up and drove them 50 feet. We need to spend money on soil investigation.

Tiebacks -- drilled & pressure grouted earth anchor systems require borings in the area of the anchor to enable the establishment of holdback capabilities, per AASHTO and others. INDOT consultants approached the job with the typical sorely lacking 1 core per job soil investigation and it resulted in our not being able to achieve the specified load capability in the system as designed. (Leon Beaty)

**Graphics:** Obtain selection criteria from Tom Davidson of University of Illinois, who is very authoritative in this area.

# Forming

## Bridge Abutment Forming

**Guideline:** Design bridge abutments to be poured before the deck is placed, and use straight as opposed to sloped faces.

Qualifications: 1.
Exceptions: 1.

**Benefits:** Reduced time and cost for construction.

**Reasons:** Pouring the back wall of a bridge abutment is very difficult because of the requirement to construct it after the deck is in place. This creates a restricted work area at the bridge end and makes it difficult to build the forms and make the pour. It would be much easier to pour the abutments before the deck is placed. Also abutment and pier details that have sloping faces to save concrete takes longer to form and are in most cases more expensive. (Walsh Construction)

**Examples:**

**Graphics: See video.**

See details below.

## Avoid Camber Ponds

**Guideline:** Move vertical curve PI's to one end or another of a bridge to avoid the ponding effect of multiple span cambered beams. (Primco Construction)

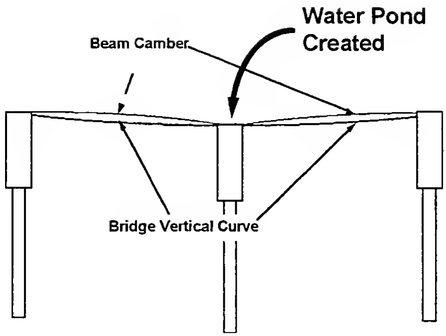
Qualifiers: 1.

Exceptions: 1.

**Benefits:** Higher quality, longer lasting finished bridges due to decreased water ponding.

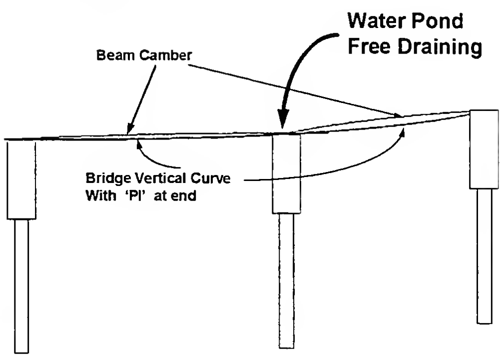
**Reason:** When bridge is located in vertical curve and the beams cambered, a ponding effect is created over the center pier.

See Ponded water Graphic Below




The solution is to move the PI to one end of the bridge.

See the solution below:




**Examples:**

Graphics: See pictures of ponded conditions created by this problem.

## Pier Cap Extensions

**Guideline:** Design pier cap extensions to enable the contractor to simply, drill, dowel, and epoxy into existing cap to tie on the extension.

Qualifiers: 1.The designer should determine if there is any reduction in the pier capacity with this option

Exceptions: 1.

**Benefits:** This option is quicker, easier, and cheaper for the contractor. (Weddle Bros. Construction/ Primco)

**Reasons:** Two common methods exist:

1. Remove concrete back to existing column reinforcement, by Jack hammering. (See video clip - Jack hammering of cap.)

2. Drill, Dowel, and Epoxy into existing cap after simply cleaning it to obtain good bond.

**Examples:**

**Graphics: Video of Pier Cap Extension Process.**

## Slope Bottom of Column Capitals

**Guideline:** Slope the bottom of column capitals to match the slope of the monolithically poured upper slab.

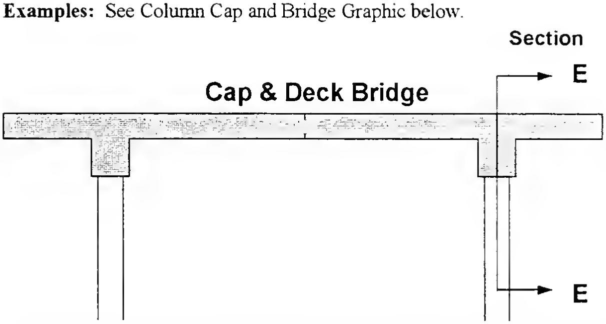
Qualifiers: 1. Is an integral cap and slab bridge

Exceptions: 1. None identified

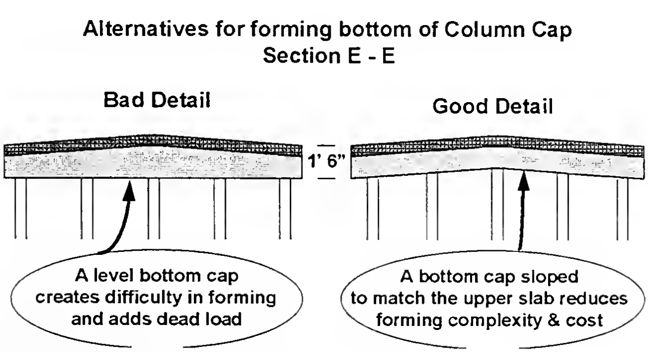
**Benefits:** Lower total bridge cost without loss of quality

**Reasons:** Forcing the bottom of a column cap to be level, adds significant complexity, forming materials, and dead load, with no apparent increase in quality or serviceability.

**Examples:** See Column Cap and Bridge Graphic below.




Note dimensional changes required at the form transition between the sloping deck and the level cap bottom. Sloping the cap bottom with the slab, eliminates the additional cost.



Confirmed sloping the bottom flange on a pile cap was cheaper, but didn't think it was a very big deal. (Switzer & Huckleberry 1983)
**Graphics:** Picture of both types of forming systems in place

## Research New Stay-in-Place Forms

**Guideline:** Stay-in-place forms should be redesigned to allow water which penetrates the slab to evaporate from the bottom of the form. A long term solution is needed which will take advantage of the labor savings associated with stay-in-place forms, provide an acceptable under finish and yet will not trap water which penetrates the slab.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** At least 10% savings exist for use of the stay in place forms at the time of construction. Over heavy traffic areas the savings is about 25 to 40% over standard forming systems.

**Reasons:** But the current type of form seals up the flow of water through the slab and results in a significant reduction in the life of the structure. Leon Beaty

**Examples:** Stay in place forms should at least be very heavily galvanized to avoid long term maintenance. But galvanizing will still only provide about a 20 to 25 year life.
Consider perforating the stay in place forms to allow water penetrating the slab to evaporate from the bottom. Expanded metal type stay-in-place bulkheads have been used for several years. If used under a bridge, however, this may provide an unacceptably rough finish. A zip off under layer may be possible and should be researched for an effective solution.

**Graphics:** Pictures of current systems and maintenance problems after 5, 10, 15 and 20 years.

## Standardize Column Diameters

**Guideline:** Standardize column diameters at 24inch +6inch increments.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Lower total cost of column construction.

**Reasons:** The extra concrete is worth it to avoid special form rental, or sonotube purchasing. (Reith Riley)

**Examples:** Pictures and description of procurement and form setup for non standard sizes.

**Graphics:**

## Standardize Forming Sizes Etc.

**Guideline:** Provide designers with standards for design of beam length, widths between beams, reinforcement, etc. together with variance costs.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Reduced cost for design, detailing, and construction.

**Reasons:** Lengths of beams, widths between beams, rebar reinforcing, negative steal over the piers, seam to change on every bridge structure. Standardization is not a criteria for design, and it should be. One of the largest costs for a contractor is building and setting the form, if that could be standardized, we would save a lot of money. This enables a contractor to standardize materials, people and procedures. For example box culverts. If the spans are the same, after you get up out of the ground, there is very little reason for not standardizing nearly everything. (Leon Beaty)

**Examples:**

**Graphics:** Show required form changes to accommodate variations typically used.
Provide charts for the costs of alternatives.

# Components

## End Section Toeplates

**Guideline:** Determine whether toeplates are to be used or not, specify clearly what is wanted, and apply the rule.

Qualifiers: 1.

Exceptions: 1.

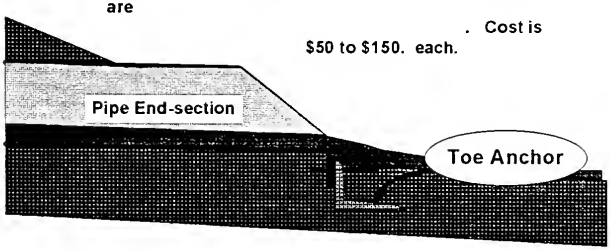
**Benefits:** Savings of $50 to $150. per toe section which are typically specified, and purchased, but not installed.

**Reasons:** Toeplates are generally specified to prevent the vortex action of the water from undermining the pipe end section. The drawings and specs often call for them, but the state doesn't want them put on.

**Examples:** Our lot has so many toe sections with state tags on them we could go into the scrap metal business. The drawings and specs call for them, and the project engineers direct us not to put them on. At 50 to 150$ each. (Contractors United)

**Graphics:**
See ToeAnchor Graphic Below

**Toe Anchors -- are designed to prevent the vortex action of the water from undermining the end section. They are . Cost is $50 to $150. each.**




## Establish a Uniform Joint Spec.

**Guideline:** INDOT needs a uniform joint specification. Don't use copper expansion joint water stop seal, use PVC or

neoprene rubber. In any case, make it clear; if only one type is acceptable, then don't put in additional special provisions to provide some other options. (Reith Riley)

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Lower cost and higher quality

**Reasons:** Pier construction joints are a major source of causing pier cap damage because it serves as a conduit for salt and water. The copper is very expensive, to purchase and use, and results in a lower quality job. (Leon Beaty)

**Examples:** It may seem amazing that some designers are still specifying the antiquated copper water-stops, but it does happen occasionally.

**Graphics:**

## Hoods on Catchbasins

**Guideline:** Clearly specify where hoods will and where they will not be required as opposed to generalized statements which are difficult to interpret at best and wrong at worst.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Reduced uncertainty and conflict in bid documents.

**Reasons:** More care should be exercised by engineers to avoid conflict and errors in this area.

**Examples:** The specification on the project we are bidding says hoods will not be required. But it has 200-type structures which the standard shows with hoods. Further, we know from experience that sanitary or combined sanitary and storm sewers normally have hoods. So do we research every one to be sure whether it is sanitary, or combined with sanitary and then include them because our experience tells us they will be needed. At $200 each, that adds up. (Contractors United)

**Graphics:** Show a picture of a hood with a $200. price tag.

## Boxed End Sections

**Guideline:** The necessity of boxed end sections should be investigated prior to use.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** As much as $100,000. savings for each one that can be eliminated.

**Reasons:** By the time they are installed, boxed endsections on pipes may cost as much as the whole pipeline. They are normally installed for increased safety in the event of a vehicular impact. They provide a 3:1 slope if the car hits one rather than the old headwall. But, they have been installed on a side where a car would have to backup into one to hit it.

**Examples:** They may cost $100,000 and if at the end of a 50-ft slope, the chance of being hit is rather remote. Their necessity should be investigated. (Reith Riley)

**Graphics:** Provide to demonstrate acceptable conditions not to install one.

# Work Area Design

## Increase Work Zone Size

**Guideline: Use crossovers and increase work zone length limits to 10 miles or longer.**

Qualifiers: 1.That it is indeed a fallacy that if we limit the contractor to 2-3 miles were going to move traffic through quicker. Because after you get the traffic down to one lane, length makes very little difference in the time it takes to move through the work area.

Exceptions: 1. Switzer & Huckleberry (1983) Confirmed the limit does exist, but did not fully agree with the notion that the only impact is at the neckdown. Their experience is that there is also some impact due to the length of the bypass.

**Benefits:** Increases construction quality and safety for both the contractor and the traveling public, and decreases cost and time for construction. On a single 10 mile reconstruction project totaling $6 million: save construction and removal of 3 crossovers at ~$50,000 ea., plus another 2-3% of the project (~$150,000) due to removal of phasing inefficiencies. Total savings ~$300,000 or ~5%, and 1 year instead of 1 & 1/2 years.

**Reasons:**

The current practice of limiting those work zones to 2 or 3 miles adds the expense of the additional crossovers and phasing.

Where crossovers are built on 4-lane roads and contractors are given one entire side of the road to work on, it has made it a lot safer for the contractors and it really hasn't impacted the traveling public that much because if they are going to be traveling through that work zone, they would be down to one lane anyway. Overall, it would be the best to allow the cross over, rather than force 1 lane rework at a time. The quality of work is better, and it costs a lot less. Especially on bridges, the time will be one third less.

**Examples:** Instead of one lane on the construction side, it creates one lane each way, both on one side of the road. This makes a much safer area to work for both the contractor and the traveling public. Most of the accidents occur in the funneling area, where you take it down from two lanes to one lane. Once you get them down to one lane, you really don't have a problem, they don't have anyplace else to go and they move along. The traffic jams and tie-ups occur at the narrowing down point, at the merging areas. And crossovers have allowed the contractor to be a lot more efficient because they have an entire side of the road to work in and they don't have to worry about traffic.

**Graphics:**

**Other Required Research:**

1. Instead of removing temporary cross overs, You could put an earth berm 3 foot high and seeded, or something like that and save $3 to 4,000, plus the cost of rebuilding a crossover when needed for road maintenance or expansion in the future. (Gross 1993)
2. Consider use of buzz strips to get traffic moved over quicker. Didn't know, but doubted it would eliminate the problem. (Switzer & Huckleberry 1983)

## Detail Phased Cross Sections

**Guideline:** Select construction limits using detailed plans and cross sections through each phase of the construction.

Qualifiers: 1. Areas with high intensity construction such as bridges and temporary roads

Exceptions: 1. Right of way constriction problems generally only occur in urban areas. (Shutt 1993)

**Benefits:** Reduced time & cost for construction of bridges and temporary facilities.

**Reasons:** INDOT contractors have suggested that temporary facilities, (runaround roads and temporary bridges), are often designed too close to the permanent structures for cost-effective construction. When it occurs, this often requires temporary shoring, reexcavation and intense construction methods, which are much more expensive and time consuming. A temporary right-of-way extension is often sought by the contractor under these circumstances.

A contractor will pay anything up to the marginal cost of alternative means of constricted construction, to obtain these increased temporary limits. This marginal cost may far exceed the market value of temporary use of the additional property. Further, temporary access arrangements can take months or in the worst case be impossible to obtain. Requiring the contractor to make them during the bid can create an expensive level of uncertainty, and can be very disruptive to project scheduling.

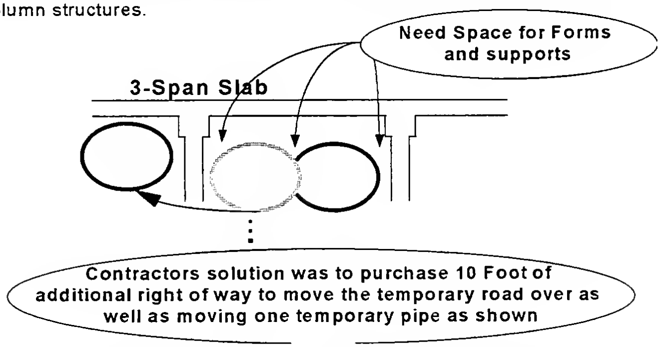
Drawing cross sections through temporary, as well as permanent facilities, provide an effective method for the designer to consider the interaction between them; and perhaps justification for increased construction limits and right of way.

**Examples:** That is absolutely true. It seems like we will go to no limits to keep from buying right-of-way. For example, on I-65 at a railroad under pass, we had to cut the slope at 1:1, and it is now almost impossible to hold. (Switzer & Huckleberry 1983)

Example 2.

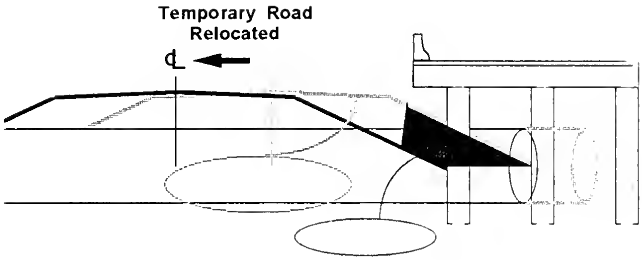
"Why do designers put the temporary road so close that the temporary drainage pipe goes underneath the new bridge? This increases the cost."

A temporary by-pass road was designed so close to the permanent bridge structure that temporary pipes protruded under the new structure and conflicted with each other and the contractors need to form the slab and column structures.




"If I've got a tight situation to work in, it is going to cost me more money. I'm either going to have to go rent some ground off somebody to work, or I have to work at a very big disadvantage."

Further, on this INDOT project the temporary bridge was designed so close to the structure that the toe of slope on the temporary dirt, and temporary road culverts run back underneath the new structure. Building according to the plans, would have required sheeting and shoring the temporary fill, and a 40-foot clear span form, in order to put in the new bridge encasements and cast the slab. The contractor bought a right of entry from the property owners and is moving the temporary over 10 feet. Often, as in this case, only the centerline of the temporary road was given. It is necessary to draw the whole temporary road with its shoulders and toe. Then, cross sections through the temporary road and bridge structure would have clearly revealed this expensive conflict. That the road would be so close, for example, that a temporary barrier would be required to prevent splattering concrete on cars during the removal of the existing bridge. The design engineer admitted not realizing his design required either procedure. (See Graphic Below.) Due to the relocation, the temporary road conflicted with trees and a residence that were beyond the original construction limits. This all could have been avoided if the designer had taken the time to do cross sections along the proposed temporary road.




Q: Referring to contractor's drawings, Were any sections like this shown on the design?
A: No. There were no sections through the bridge. Sections were made on the approaches up to the end of the old bridge, but not on the bridge itself. In addition, it is often found that contours, and obstacles (trees, homes, utilities, etc.) beyond the constricted ROW are incorrect and incomplete, rendering redesign by the contractor very difficult and expensive, especially during the heat of a bid.

On highway 38, the design had 2 strips on the outside and **9-10 feet left in the middle zone** to work in. It was a virtual impossibility. Well, the contractor came up with an alternate plan and we did some modifications. Historically, designers have tried to ignore this problem, hoping it will go away, or that maybe it's not that important. Sometimes it is a major issue out there on construction. (Switzer & Huckleberry 1983)

Guard rail specifications in Indiana change more than the weather. On one job we didn't have **enough right-of-way to flair out the end of the guard rail**. We had to run the guard rail way up the road to the point the sides were large enough to terminate the guard rail and meet federal standards. (Switzer & Huckleberry 1983)

Often, when building a bridge, the **construction limits will be right smack on the fence... we can't build it, without encroaching on someone's property. We would be happy to have enough right-of-way to build what is on the plans. I mean that the plans say to put a slope in at 3:1 and you go to lay it out and a 3:1 slope won't fit within the right-of-way. There needs to be a better look at the room available and make sure what is called for is constructable within the limits given.**

**When the field engineers are attempting to redevelop something that was there before; often the contractor and field engineer must alter even the best design somewhat. If they don't want to give you any more right-of-way distance, then you just have to cram it is there ... to make it work, like on black creek where it takes a billy goat to mow.**

**The designer needs to draw cross sections through each section of the structure, for each phase of the project. Then and only then can the designer adequately visualize what it will take to build the project during those phases.** (Leon Beaty)

**Earth retention during phases is typically considered incidental and included in other items. It could be very substantial or even eliminated if the engineer would do the cross sections and think about it before the design.** (Leon Beaty)

**Graphics:** Pictures or video clips of the **red lined** items

Also See Constructability Concepts
**Provide 5 Ft ROW From Construction Limits**
**Clear Legal Access**

## Complete Run Around Design

**Guideline:** Complete temporary run around design, including toes and cross sections, and extend the run-around beyond construction limits before the tie in.

Qualifiers: 1. A run around should be quantified as the most economical alternative. (See **Work Area Size**.)

Exceptions: 1.

**Benefits:** More realistic conceptualization and economical design of temporary systems for traffic maintenance. Less frequent need for field redesign with corresponding time delays and change orders.

**Reasons:** The design practice of identifying only the centerline of a temporary runaround often results serious plan deficiencies. The extent of the slopes and toe, and their interaction with utilities (existing, temporary and new), and with areas required to build the new facilities; are difficult to design without the aid of cross sections.

**Examples:** Forcing cross sections through strategic areas and standards on runarounds would be the best way to control/design them for constructability. More frequent sections would be required than every even station. Runarounds are often long enough to build the structure, but not to make the tie ins.

To shorten the project, designers will bring the temporary run around back in within the construction limits, and then put in the special provisions that you can't close the road. Well, we've often had to have a 20 day shut down just to make the tie-in, a problem which could have been avoided if this concept had been applied. If you're going to have a run around, make it far enough away that you can do your work. (Switzer & Huckleberry 1983)

**Graphics:** Typical plan with only the centerline shown and no toe, or cross sections, utilities, or conflicting structures identified

# Existing Structures

## Very Old Existing Structures

**Guideline:** Identify the existence of and quantify the scope of very old existing structures. Once quantified, if all or some of the old structure must be removed, describe it and list its removal as separate bid item.

Qualifiers: 1.
Exceptions: 1.

**Benefits:** Enables consideration of the existence of such structures during design, and alternatives to avoid rather than remove them. Reduces construction costs and required redesign during construction.

**Reasons:** It is very expensive to run into an unexpected, class X, unclassified foundation excavation, which is demolition of the structure previous to the one we are removing in order to build a new bridge. Often, the old foundation is very large, and could have been anticipated and discovered with a little historical research during the discovery phase of design. The problem is not having any idea what is under the existing structure, until its discovery halts progress on other activities. If bid as a lump sum, it is often combined with the radically different unit costs of removing approaches, railing, false-work timbers, slabs, etc. This results in an unbalanced condition in the unit price of this bid item.

**Examples:** We ran into a preexisting structure (the old interurban electric rail-car system ~ 1980 vintage). No one discovered it was there during design. It is **very costly to probe/dig around to discover what is there during construction, while other activities must be halted**. If suspected, (and it should be suspected if it is in the corridor as shown on old drawings that are still available in the library), it should be probed for and identified during the design. Ask around to talk to old knowledgeable people. That is what we do. It should be identified to reduce unknowns. (Shutt 1993)

**Graphics:** Pictures of the exposed interurban, historical records, field probing and impact on other construction operations.

# Road Interface

## Bridge-Road Transition

**Guideline:** Include the upgrade of just enough approach road in front and behind of a bridge to construct it, no more.

Qualifiers: 1.

Exceptions: 1. If the upgrade can continue to an intersection, or other natural transition, it may be economically justifiable to do it with the bridge.

**Benefits:** Reduced cost for construction of the approach. Also, enables a closer time match between the expenditure of funds and the public benefit of those expenditures.

**Reasons:** The design practice of improving a road 6-700 feet on either side of a bridge cost 2 to 2 and 1/2 times as much as the same work performed during the upgrade of the balance of the roadway. Mainline road work requires at least one half to 1 mile length to be productive. Just enough to put the bridge in is fine, but it is a waste to go beyond that because the road just necks down anyway, which eliminates any significant public benefit until the balance of the road is upgraded. Consider time value of money concepts, etc. (Switzer & Huckleberry 1983)

**Examples:**
Get some typical ones and exceptions that might make since to go ahead with at the time of the bridge construction.

**Graphics:**

# Roads

# Work Area Design

## Increase Work Zone Size

**Guideline:** Use crossovers and increase work zone length limits to 10 miles or longer.

Double click this hyper link to go this Lesson Learned under Bridges-Work Area Design

# Components

## Hoods on Catchbasins

**Guideline:** Clearly specify where hoods will and where they will not be required as opposed to generalized statements which are difficult to interpret at best and wrong at worst.

Double click this hyper link to go this Lesson Learned under Bridge-Components

## New Curbs on Existing Drives

**Guideline:** Design for turning radius reduction caused by new curbs on existing drives. An acceptable guideline needs to be developed to provide these benefits.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Increases public access, and satisfaction with upgrade performed by INDOT, while it reduces required rework. Results in more productive construction by providing actual requirements during design.

**Reasons:** Current practice provides for no direct contact made with property owners whose driveways we are replacing unless we are buying right-of-way from them. Legally, all commercial access permits are revocable, but one just doesn't go out and put people out of business.

When roads are widened or rehabilitated and curbs are added to existing drives, considerations must be given to restricted turning radius caused by the curb which replaces an open shoulder. If not, often access is severely restricted or even eliminated for semi's or large RV's which have previously utilized such drives. The result is field rework or redesign. (Switzer & Huckleberry 1983)

**Examples:** On this highway 38 project, some of the things people were doing were illegal and some were unsafe, but the things we are doing will make some of the businesses nonfunctional. We're having a little trouble with deaf ears when we call for help. You might consider this a construction problem, but in my opinion, it is a design problem.

One typical example is moving Ferrel's driveway over to match the shopping center drive way, Now supposedly, all these people get notice in the paper of a public hearing, but what do they do? Figure it doesn't affect them. So anyway, this Ferrel drive was moved down to match up opposite with the one coming out of the mall. Well, if you move Ferrel's entrance drive 70-80 feet east and then look at what it is going to happen to the parking set up in there, it is a disaster, because semi's have to go back behind the building . . .

**Graphics:** Video clip of RV attempting to negotiate on an existing drive with a new curb.

# Drainage

## Properly Size Manholes

**Guideline:** Size manholes at least large enough to avoid destroying the structure of the manhole when tying in specified pipes.

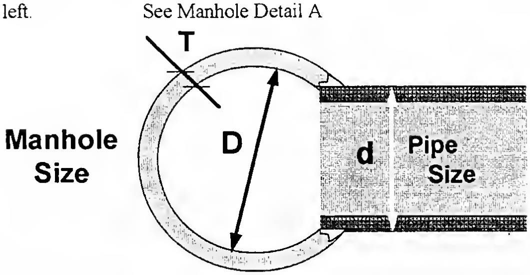
Qualifiers: 1.

Exceptions: 1.

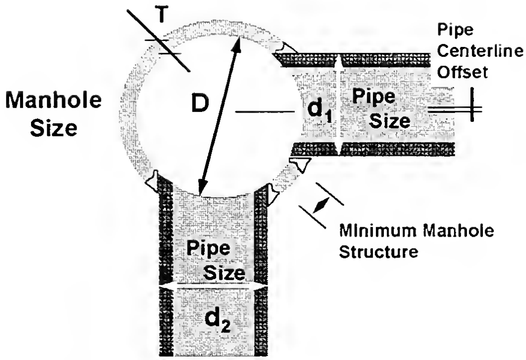
**Benefits:** Reduces design errors, and change orders and jobsite delays and disruption which result from them.

**Reasons:** Engineers typically don't know how to design manholes. Many times manholes are sized inappropriately for the pipes it is servicing. (Contractors United)

**Examples:** Ex. a 4-Ft diameter manhole for a 4-ft pipe. Or if 3 @24 inch pipes are put into a 4-ft manhole, you don't have a structure left. See Manhole Detail A



See Manhole Detail B




**Graphics: Contact Horn precast for the details on how to design the size of manholes. Chad Blackwell in Columbus.**

## Boxed End Sections

**Guideline:** The necessity of boxed end sections should be investigated prior to use.

Double Click this hyperlink to see this Lesson Learned under Bridge-Components

## Interior and Exterior Drains

**Guideline:** Do not use interior drains, and install the exterior drain fabric as shown.

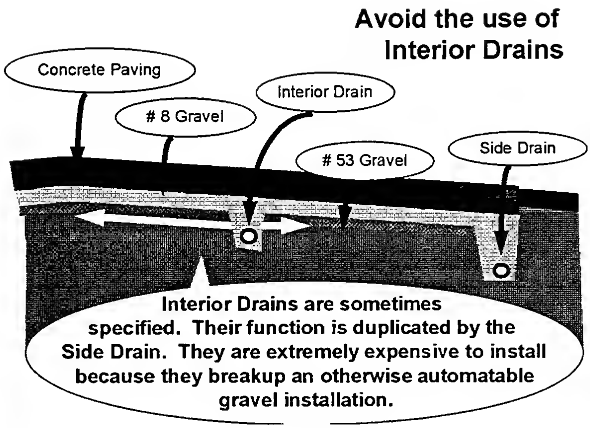
Qualifiers: 1.
Exceptions: 1.

**Benefits:** Avoids cutting up an efficient, mainline installation process, with the associated time and cost impacts.

**Reasons:** #8 and #53 gravels are currently installed using pavers. An interior drain with its associated filter fabric gets in the way of a paver's automatic trimmer. It often snags the fabric and tears out large sections which must be replaced by hand. Further, an additional drain at the center barrier does not appear useful. All that is necessary is one at the outside, the inside one is wasted. (Reith Riley)

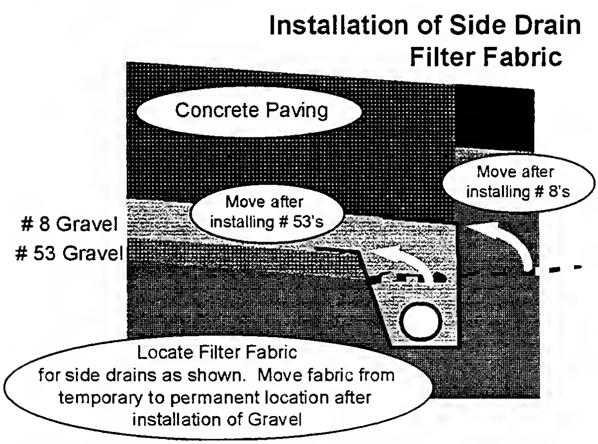
**Examples:** Placing an interior longitudinal drain at a crowned center or somewhere down the slope in the center between the crown and the edge drain is a waste of material and very costly to install because of the patchwork phasing required to dig the interior drain, place the #8 stone around it, and then place the impervious #53 gravel up next to it, without going over the top, before one can place the #8's on the top. It is very time consuming without any apparent added value. Further, the state complains about us getting #53 over the drains. It is a big mess and very difficult to control. If there is not a barrier wall in the middle they have only one the one drain anyway, so why do they add a drain when there is a barrier wall?

See Interior DrainDetail Below




We need a full review of the use of underdrains, (interior and exterior). With some designs, the fabric could be hit by the trimmer. This is an operations type problem. Considerable confusion exists about the appropriate location of this fabric to protect the #8 stone from plugging up with sediment and still enable automated trimmers to be employed without them snagging the filter fabric which requires a hand operation to fix.

See Exterior Drain Detail Below




Installation of filter fabric as shown around the exterior drain prevents infiltration, as well as, allowing the use of pavers to install the gravel. (Reith Riley)

## Cleanouts on Edge Drains

**Guideline:** Don't use cleanouts on edge drains. Simply check them following construction to be sure they are not crushed or full of construction rubble.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Eliminates the cost of the cleanouts and the disruption to mainline highway construction which they cause.

**Reasons:** Mainline highway economies of scale are available only when protruding items (like edge drain cleanouts), which tend to break up continuous functions, are eliminated Further, edge drains which are properly installed seldom if ever plug up. To use them is costing the state a lot of money with no apparent benefit.

**Examples:** We have removed or reworked hundreds of miles of edge drain and have never found one that was plugged up. Cleanouts on edge drains, which have recently started showing up on bid documents, do not appear necessary. If checked and clear (not crushed or full of construction rubble) after construction, the drains seldom if ever plug up. The cleanouts appear to be a waste of money. (Reith Riley)

**Graphics:** Picture of edge drain cleanouts and equipment and manual labor necessary to work around them.

# Earthwork

## Define Line of Sight Contours

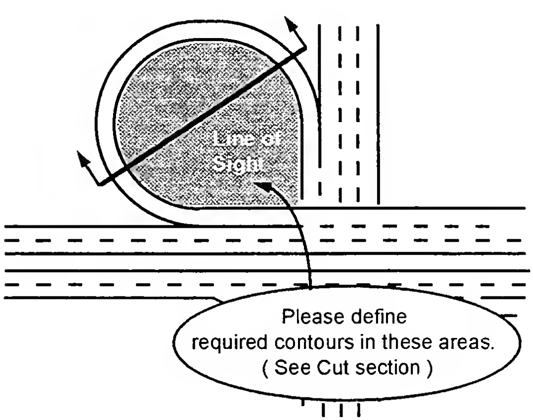
**Guideline:** Define clearly what contours can be produced by wasting on site. If visibility must be maintained, define it, with contours.

Qualifiers: 1.
Exceptions: 1.

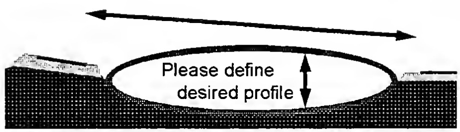
**Benefits:** Lower excavated or borrowed material movement or purchase costs on current and future projects.

**Reasons:** Wasting 50,000 CY on site rather than including a haul and dump fee, can be a large savings. This may provide a source of dirt for future expansions. (Contractors United)

**Examples:** See Line Of Site Plan View




and Line Of Site Elevation Below




The profile which will provide an acceptable line of sight as well as appropriate drainage, should be contoured. The volume of potential material is very significant.

**Graphics:**

## Bituminous Coated Underlayments

**Guideline:** Do not specify bituminous coated 5-c #8 rock under asphalt for small sections which are surrounded by other types of underlayment.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** More cost-effective repair and patching.

**Reasons:** Using bituminous coated 5-c #8 rock under asphalt for small sections which are surrounded by other types of underlayment are very expensive and don't appear to serve any useful purpose.

**Examples:** For example when widening an intersection. Half loads or even full loads are used to hold the heat. If there is only a half load requirement the material is very expensive. Eight ton loads are too small to go 20 miles. So a half load would be wasted just to hold the heat. Reith Riley

**Graphics:**

# Linear Grading

## Implement Current Linear Grading Policy

**Guideline:** Implement current linear grading policy.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Elimination of a vast quantity of unknowns and resulting uncertainty at bid time.

**Reasons:** Linear grading is horrible, to say the least. A solution is in place which will be acceptable if implemented. (Contractors United)

**Examples:** Include text of current recommendation.

**Graphics:** As required to explain

# Concrete Paving

## Specify Standard Concrete Paving Widths

**Guideline:** Establish and design to standard widths of concrete paving. (Eg. 12, 16 or 24 feet wide only) Reith Riley

Qualifiers: 1.
Exceptions: 1.

**Benefits:** Time and cost savings

**Reasons:** If the design requires a change from the standard 16 foot to 15 ft or 17 ft, it takes 2 days at $600. per day (direct cost) each way to change width on a paver. The same holds true to change one from 24 to 25 ft. Further, if specified, the odd width adjustment is required for each phase of such a project. So when a paver must be at 24 feet for most work and then for one job we have to keep changing its width for several phases, the cost may total ten, twenty, or even $30,000 plus the opportunity cost associated with not paving. When we're changing width, were not paving.

The season is short, so this cost requirement is substantial. Is the extra, 'odd' foot really warranted? Slip form pavers do not change width easily. Every time after the change, the operators must zero it out and get the crown right etc.

**Examples:** Shoulder, concrete width variations to avoid a 2-foot stone shoulder next to a guardrail is another example. When the concrete changes from 12 to 10 ft wide, the contractor must skip the 10 foot sections and comeback and pour them separately. (See Video) Understanding that the extra 2 feet next to the guardrail is to prevent the wheel movement associated with the elevation transition to gravel (which would occur, if the extension weren't there,) it is probably cheaper to pay for the additional 2 feet rather than make the transition if it is not too long (< ???? Feet). Tapering the concrete width is and even bigger chore, because a temporary form must be placed to form the taper and the machine extended to the widest section.

Changing the width of an asphalt paver is a little easier. They are hydraulically extended except for the augers which take a little time to extend. The augers are generally extended only if several days of paving at the extended width is involved. The auger extension enables a better distribution in the extended areas without extensive manual labor.

**Graphics:** See Reith Riley tape.

## Longitudinal Joint Spacing

**Guideline:** Don't install joints that are not needed.

Qualifiers: 1.

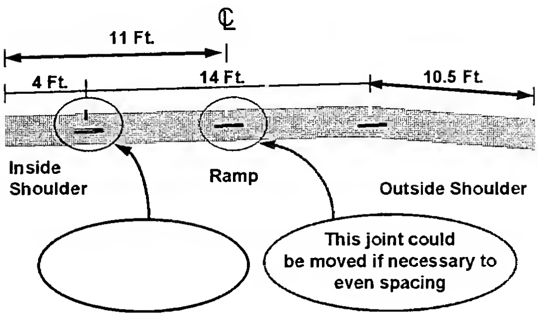
Exceptions: 1.

**Benefits:** Avoids all the detriments associated with joints in addition to their construction costs.

**Reasons:** Arguments for the joint, include the need for a hinged joint to accommodate the wheel loading out there. But why introduce an additional joint with all the infiltration problems that creates, when random cracking doesn't occur anyway on 16 foot wide ramps? (Reith Riley)

**Examples:** Break out dowels are often specified for the longitudinal joint along a 4 ft inside shoulder. The use of dowel baskets with a sawed joint has been given as an alternate to avoid random cracking. But, the joint is not necessary. See Longitudinal Joint Spacing Detail Below.

**Typical Ramp Dowel Layout**




**Graphics:**

## Standardize Forming Sizes Etc.

**Guideline:** Provide designers with standards for design of beam length, widths between beams, reinforcement, etc. together with variance costs.

Double click on this hyperlink to See this Lesson Learned under Bridges-Forming

# Contracts

## Plans

## Avoid Overloaded Drawings

**Guideline:** Spread information over multiple pages in the plans rather than overlaying too much on one drawing.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** More accurate bidding and fewer construction errors, and hence lower net cost.

**Reasons:** Indiana designers often overlay too much information on the drawings. This is causing confusion in reading and difficulty interpreting the plans, especially when they are reduced to half size (which is really 1/4 size by area). Creating doubt or uncertainty in the interpretation or intent of the plans increases the probability of making mistakes during bidding and construction. Plans that are clear and uncluttered increase a contractors confidence during bidding and reduce the need for contingencies. (Walsh Construction / others)

**Examples:** One solution is to spread the information over multiple pages. For example, a road drawing could show the roadway and its profile and a separate pipe drawing could show the drainage and utility structures for the same section of roadway.

**Graphics:** See example of overloaded drawing below.

## Reanalyze Achieved Plans

**Guideline:** Designs achieved more than 1 year must be seriously reanalyzed for interim changes since the design. Make sure pay items include all items required for construction. (Switzer & Huckleberry 1983)

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Reduced errors, omissions, and need for field redesign. With resulting reduction in contract cost, change orders, contractor overhead, INDOT overhead, and time for construction due to changes in the interim.

**Reasons:** It is not unusual for projects to be designed and then, due primarily to budget restrictions, to be archived for 1 to 10 years or more. (Switzer & Huckleberry 1983) Contractors and INDOT district personnel report little effort to update old designs prior to bidding.

**Examples:**

We had piling going through 26 fiber optic cables from Indiana Bell. As a result, the structure had to be built around a steel box containing those cables. The **additional cost was about $250,000** to build around the cables. After the fact, Indiana Bell estimated the cost to move the cables would have been only about $150,000. The design did not consider the steel box which had been added during the 10 years since the design. This error was discovered immediately, and involved so many people, that nobody could make a decision. It was on our critical path and severely impacted our job. After this redesign, my engineer discovered that the centerline was off 2 and 1/2 feet. So, it went back into redesign. This sort of thing happens when a set of plans has been on the shelf for that long, and is not seriously reanalyzed for interim changes since the design. (Shutt 1993)

Sometime before they go out to bid, an archived drawing needs to be reviewed by looking through the contract items and conducting a site inspection to make sure that everything still makes sense; probably by someone with some construction knowledge. **Often there will have been changes**; buildings added in this area or that, **which don't show up on the plans**. The designer must then determine how are we going to get people in and out of the added buildings when the road is torn up. There may be no driveway according to the plans. When not addressed in design, it creates a problem between the state inspector and the contractor because they have to try to solve them out here in the field. (Gross 1993)

A lot of times in field check procedures, they haven't looked very well to compare their plans with actual field conditions. We have been told this happens for various reasons. Sometimes a designer comes out and looks at the job and goes back and designs it and never comes back to **compare the design with field conditions**. We have had jobs that have been put out for bid that have items missing, there are work items shown in the plans for which there are no pay items set up. We have a simple resurface job now in the Crawfordsville area where we had curb removed, but no pay item to put the curb back. It seems like something like that is very basic. If someone would look through the proposal, they can see that curb is being removed, but there is not any pay item to put any curb back. (Gross 1993)

We are working on a couple of projects right now designed by outside consultants 8-10 years ago, and they have been on the shelf. They have pulled them off the shelf and put a new proposal book together and been put out for bid. Items are in there which have changed. The specs have changed, there are items in there which the state no longer does that way. The project has changed because there has been other work done in that area during the 8-10 year period. That totally changes the scope of work; so you have this set of plans which really aren't very well related to the area at this time. (Gross 1993)

**Graphics:** Suggested a standard computerized system for updating old designs prior to bidding. To include a list of all changes in spec's made since the design date that might affect that job. (Switzer & Huckleberry 1983)

## Redesign combined plans

**Guideline:** Redesign combined plans.

Qualifiers: 1. The more remote in time combined designs are, the more critical is a coordinated reanalysis.

Exceptions: 1.

**Benefits:** Avoids major confusion to the traveling public, overlap in bid items, and alignment differences from one job to the other. Provides for uniform specifications, cross sections and traffic control plans.

**Reasons:** When 2 or more projects are combined (bid together, and/or performed simultaneously), a new design condition is imposed requiring a coordinating redesign of the combined project.

**Examples:** When 2 projects come together and uncoordinated traffic control systems overlap, it causes a **major confusion to the traveling public**. On Highway 40 for example, they had to redesign the traffic control after the bid. (Shutt 1993)

Another example is of two projects that were put together under one contract. Each was designed by a different designer/consultant and a coordinated design was never done before the bid. There was **overlap in bid items**. The **alignment was different at the transition** from one job to the other. They had **different specifications** and **different cross sections**, the jobs were almost unrelated, they just happen to butt up next to each other. Although one was designed some years back, they decided to put them together, and nobody looked at the consequences. When they were put together, there was **no coordinated traffic control plan**, they had been designed completely independent and could not be worked that way. (Gross 1993)

On state highway 25 up in Lafayette, somebody designed a bridge and somebody else a road, and a third person the signal plan. Then all 3 projects were combined. We caught many errors; the **typical sections on the bridge plan had a different elevation from the road plan**. The bridge design assumed the road work was completed. When run together, **the bridge traffic plan had traffic running into a non existent road area**. We had to come in with sheeting to hold the sides up for traffic on a run around. (Switzer & Huckleberry 1983)

**Graphics:**

This is a frequently occurring problem, and a standard needs to be established for combining bids.

## INDOT Should Check Consultant Designs

**Guideline:** Don't use consultants to check other consultants work. (Leon Beaty)

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Increase quality control and value engineering of consulting services

**Reasons:** Consultants are enormously reluctant to criticize another professional work for other than safety or code related concerns. Value engineering will not be performed unless INDOT does the review.

**Examples:**

**Graphics:**

## Field Verify Existing Structures

**Guideline:** Designers should use old as-built drawings if possible, and redline all dimensions which are critical to the upgrade or removal. These dimensions must be field verified by an organization such as that proposed for the Joint Utility Commission.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Lower net time and cost for construction through more accurate designs. Often sufficient time to field measure and correct design deficiencies is not available for the contractor. Steel and/or precast elements

**Reasons:** The most economical alternatives cannot be considered if inaccurate or incomplete information is used in design.

**Examples:** It has been our experience that as-built plans are not accurate if they are <u>less</u> than 25 years old. (Leon Beaty)

When existing structures are rehabilitated, asbuilts rather than simply an old set of plans should be used to understand the correct existing elevation of the beams for instance. On a Reith Riley project, the old bridge elevations were not verified and turned out to be incorrect. As a consequence the bridge deck thickness could not be maintained and still meet the elevation of the approach paving or achieve the new super-elevations designed throughout the bridge structure. (Reith Riley)

**Graphics:** Picture of precast beams ordered too long due to incorrect existing drawings and insufficient time to field measure.

## Use Construction Schedules

**Guideline:** Low bidders should submit a schedule at the preconstruction conference.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Provides the state and the contractor a tool to better coordinate construction and related activities.

**Reasons:** Informs the state what the contractors plans are and helps the contractor to defend critical path delays. It is a good tool for both the contractor and INDOT. (Reith Riley)

**Examples:** Provide examples of scheduling types with advantages and disadvantages of each.

**Graphics:** As required to demonstrate.

## Notes on Drawings

**Guideline:** Place all the notes in one place, eliminating stray notes. And describe them fully in the special provisions.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** This makes bidding more accurate. (Reith Riley)

**Reasons:** This is one of INDOT Contractors the most prevalent requests.

**Examples:** Show example of properly organized document set.

**Graphics:**

## Dimensions on Drawings

**Guideline:** Put individual, overall, and especially slope dimensions prolifically throughout drawings, not in just one place. Make sure all letters and numerals are legible when reduced to half size.

Qualifiers: 1.
Exceptions: 1.

**Benefits:** Increases contractor understanding of designer intent.

**Reasons:** Design drawings are often used by field personnel without engineering training. If dimensions are not available, it increases the level of engineering training required to understand and derive them. Experienced field personnel with engineering training are not cheep. When selecting character point size, remember when a drawing is reduced to half size, which will be used in the field, point sizes and all other items are actually reduced to 1/4th their original size. (A 32-point character becomes an 8-point, etc.)

**Examples:** Include additional dimensions. Larry (of Reith Riley), will redline a set of plans and send them to us.

**Graphics:** See 'Half Size' Reduction Chart Below, showing the visual effect of reduction'.

| Full Size | Reduces to | @ '1/2 ' Size |
|---|---|---|
| 3.2 Ax | → | 3.2 Ax |
| 338 sx | → | 338 sx |
| 344 s8 | → | 344 s8 |
| 782 cs | → | 782 cs |
| 140 pq | → | 140 pq |

Note, actual reduction is to 1/4 of original size

## Skewed End Bent Views

**Guideline:** One view of an end bent provided on a skew should not be specified as typical-rotated-180-degrees for the other end. Provide the rotated view as well. (Reith Riley)

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Increase construction productivity and accuracy.

**Reasons:** To do otherwise results in much confusion.

**Examples:** Show some.

**Graphics:**

# Traffic Maintenance

## Center Lane Closure

**Guideline:** Seek another alternative to a work envelope with traffic flowing on both sides.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Center lane closures are so dangerous and expensive that they can be characterized as nonconstructable.

**Reasons:** With a center-lane closure there is no way in or out for the material and equipment deliveries, (because there is traffic on either side). After the barrier walls are set around a center lane on such a project, the middle lane access was restricted to 150', so at the end there was 150' to get trucks backed up, turned around, and merged into traffic.

**Examples:** Such a traffic plan looked like it would work on paper but there was a much better way to go about it. Maintenance of traffic which was designed for 4 to 5 different phases, was redesigned by the contractor to be done in only two phases. Ten foot shoulders were widened to 12' which produced enough room to constrict the inside lane where crossover was possible. This eliminated 2 phases and the center-lane closure.

**Graphics:** Take a picture of this situation to show what is happening in the field to the construction operations. Also, the **excavator would have been swinging around and overhanging into traffic lanes**.

## Traffic Control Plans

**Guideline:** A well conceived and documented traffic control plan should be a standard requirement of every design. And should inclued cross sections through temporary conditions and facilities.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Reduced confusion and increased safety to the traveling public as well as lower contract time, cost and increased safety for the contractor.

**Reasons:** Designers are currently forced to put a traffic control plan in the design, but the quality of such plans should be improved. (Switzer & Huckleberry 1983) Traffic control is one of the bigger issues that design people have a problem understanding if they don't have a lot of field experience. (Gross 1993) It was observed that frequent and judiciously located cross sections through temporary conditions and facilities (including utilities) could help the designers avoid nearly all the problem discovered by the research team.

Through experience, many contractors have developed considerable expertise in this area. Although a design is necessary to establish required level of service and other design parameters, considerable flexibility should be

maintained by the department to encourage contractor redesign; which frequently results in significant benefit for all.
**Examples:** 'The Attica job was not supposed to shut 55 down, but we had 15 to 20 inches difference between the old and new bridge, so we had to reconstruct the approach. The bridge is right where highway 41 goes by and 51 'T's in. Well, we were supposed to maintain traffic and rebuild the whole 16-inches deep bituminous approach section. There was not enough width to maintain the type of traffic involved; you've got semi's and every thing else . . . So we finally got approval on a weeks shutdown and worked nights. We were supposed to do that during the day 1/2 at a time, but it was impossible.' Cross sections drawn through the temporary phases, would have clearly demonstrated the difficulties with the proposed design. (Switzer & Huckleberry 1983)

**Graphics:** Examples of good, and poor traffic plans with their field implementation.

## Night Watchman

**Guideline:** Alternatives to this very expensive provision should be considered. If a watchman is necessary, state specifically in the special provisions that 'a night watchman will be required', and during what times, days, and seasons. And provide a bid item for it to accommodate any changes. (Contractors United)

Qualifiers: 1.A night watchman is to change a light bulb, or for when a car plows through a traffic control setup and wipes every thing out. But for such an event the police are routinely given contractor superintendent home phone numbers. Since the police are going to be involved, the superintendent or an assistant would surely be contacted. They can get people out there to fix it. There may be some legal issues, (which the contractors are not aware of) justifying the inclusion of the watchman in some cases. But, with the current 'required when traffic lanes are restricted' phraseology, contractors don't know whether to include the cost of a watchman or not.

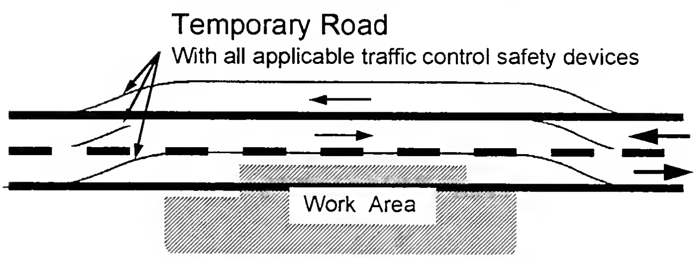
Exceptions: 1.

**Benefits:** The cost of a night watchman 12 hours a day for 6 days and 24 hours on Sunday for 2 years is about a $100,000 item.
Alternatives include a security service checking the job on a regular basis at a cost of @$10,000 or sensing devices, or arrangements with the police, or a man in the neighborhood.
If the design engineer is unsure of the need at the time of the bid, it should be listed as a bid item, then if it is found unnecessary, it won't be paid.

**Reasons:** In the proposal book, it normally states that a night watchman will be required when traffic lanes are restricted. What constitutes a restriction, however, is often open for negotiation, and the interpretation and enforcement of this provision varies widely from division to division. This provision must be rendered more specific so that contractors are on equal terms and don't have to guess what to do, or what to bid.

**Examples:** When there is an existing 2 lane roadway, and all that is required is to put in some temporary widening and move the two lanes over, is that restricted? There is still a full two-lane-of-travel thoroughfare for example. See 'Restriction' Graphic Below:

## IS THIS A RESTRICTED CONDITION ?




## Pay Items

### Scope Reinforced Earth Pay Items

**Guideline:** Define the scope of work to be included in each Reinforced Earth pay item. Also, care should be taken to match the top of the reinforced earth walls with the adjacent roadway elevation.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** More accurate bidding and payment for contractors, resulting in less confusion when scope of work changes during the coarse of a project. Also better historical unit costs will be available for value engineering analysis if it is known what work is included in each pay item.

**Reasons:** For reinforced earth structures, the scope of work associated with standard pay items is not well defined. For example, in what pay item should a reinforced-earth-foundation excavation be included; common excavation, or one of the reinforced earth pay items? (Walsh Construction)

**Examples:**

(See video)

**Graphics:**

### Make Shear Studs a Pay Item

**Guideline:** Make shear studs a separate pay item.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** To clear up the quantity required at the time of the bid.

**Reasons:** Required spacing is often not clear and a unit price at the time of the bid would clear up required costs. (Contractors United)

**Examples:**

**Graphics:**

## Pay Item for Top Soil Dressing

**Guideline:** Create a separate pay item for dressing slopes and ditches with top soil.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Increases contract specificity with an associated increase in fairness to both contractors and the state.

**Reasons:** If this is not done, it becomes an absorb item which the contractor has to guess about, and include somewhere. If a separate bid item, when it is needed, the state will pay for it, if not, they wont. (Reith Riley)

**Examples:** Show accounting for inclusion as an absorb item.

**Graphics:**

## Reduce Catch-All Items

**Guideline:** Include specific bid items for significant items that would otherwise be included in the catch all.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Reduces uncertainty and resulting contingencies at the time of the bid.

**Reasons:** Putting everything not otherwise included into a catchall item like clearing right-of-way may result in front end loading. To prevent that, the state sometimes limits the dollar amount which can be put into this item. But to do so has at times required that the contractors bid clearing right-of-way at 1/2 its value. This inconsistency can be eliminated by including more specific bid items that would otherwise be included in the catch all. (Contractors United)

**Examples:**

**Graphics:**

## Effect of Pay Item Errors

**Guideline:** Understanding how contractors prepare a bid for a pay item and can profit from either over or understated quantities on pay items, should motivate designers to be more accurate and provide better detail in an attempt to eliminate errors before the bid.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** More accurate bid documents allow the competitive system to select the low bidder based on the contractor with the highest productivity, rather then the ones most willing to unbalance their bids and/or perform legal maneuverings after the bid. Eventually, this encourages innovation and contractors to spend their time and overhead to increase their productivity rather than on how to beat the system.

**Reasons:** Contractors feel forced to unbalance a bid to be low when INDOT makes errors on the bid documents. For example, '*if we do the cut and fill calculations on a project and find that the bid item for 7,500 CY of cut and waste will not be required, we will bid that $5/CY item at 50 cents, or a penny.*' They feel this makes their total bid lower,

while not hurting the state because the item will not be billed anyway.

If the quantity listed is too small, ie. there will be more actually done then the bid quantity shown, *'then I would double my unit price for that bid item, and take the dollar amount out of something else, so the total bid is the same. But when the quantity goes over the bid quantity, I get the profit.'* Contractors commonly reason further that if some contractors don't analyze the documents as well, or want to be a *'nice guy'*, then their bid will be higher by that amount.

While on the surface, this reasoning appears valid, a deeper probe reveals that a lower bid, unbalanced in this manner, is just that, a lower bid. Regardless of what other competitive or non competitive pricing exists in the bid, it is lower by the amount of the unbalance. If INDOT creates this situation (with the error), and allows it to be successful (which it routinely does); to the extent of the unbalance thus created, the state is selecting the contractor, not based on productivity or competition for lower profit, but on a contractors willingness to play the unbalancing game. Further, higher profit and lower productivity can be embedded in such a successful bid to the extent that one contractor is willing to gamble on unbalancing relative to another. While difficult to quantify, the state does indeed pay for this relative differential, as well as perpetrate its continuance through opportunistic errors and their unwillingness or inability to enforce laws against unbalanced bids.

Providing calculations on how the engineers come up with their units may help reduce this costly problem. It would be very helpful to have all the engineers calculations on volumes for both the yardage calculations with factors for loose, or compacted as well as factors for tons per yard. *'We check all quantities before the letting. What is included and how much is very important to know. It is a real issue where we don't agree. We need those calculations to sort it out. Did they make an error, or did we? Or is it a difference in our understanding of somebodies intent? Information is going to yield the best price. Ohio does that, for information only, a page or two entitled asphalt calculations etc. and they will run through how they came up with the various types of mixed quantities, and dirt calculations. Sometimes the INDOT field office has a copy of the calculations, but they are unavailable to contractors at the time of the bid.'*

Contractors are willing to pay for the calculations. And, it may be something that can put on existing prints, but when an error exists, providing the engineers calculations will have a variety of impacts. These impacts will depend on the nature of the error and to a large extent on the engineers relationship with a friendly contractor, as well as that contractors time and willingness to share with the engineer errors and omissions discovered during their review. Contractors are motivated to make money as well as protect their integrity to enable them to continue to make money in the long run. What a contractor will do when they discover an error, depends on how they view the tradeoff between these often competing ideals, as well as how they think their competition will deal with discovery of the same error.

Errors which can be construed to the advantage of the contractor, will not be revealed until an appropriate time after the bid. If a contractor feels that his competition is more unscrupulous than he, and will attempt to take greater advantage of the error than he dares to take, then such a contractor will be motivated to have an addendum issued to equalize the playing field. To provide the requested engineering calculations is not to change the basic nature of American business. It will, in some cases, confirm what a contractor finds to be in error, and help them more clearly understand how to take advantage of it. On the other hand, the contractor that feels he could win anyway on even ground, who wants to develop or maintain excellent relations with the engineer of record; may for reasons beyond the project at hand, be willing to inform the engineer of his errors and omissions.

This is a not so rare situation in the industry, and one to be carefully cultivated by design engineers. It should be observed that this type of relationship is most likely between companies operating in the private sector as well as for INDOT. Further, it is operative whether the engineer provides the breakdown of his bid item quantities or not. Finally, it should be clear that the only way to clearly eliminate this type of game, is to eliminate the error. So, the hope is that through understanding of how the game is played, engineers will realize they must not over or under estimate bid item quantities, and will more carefully and accurately prepare the bid documents.

**Examples:**

All calculations may not be necessary. Areas and yields are the problem. For example type O stone may have 100,000 tons required on the job from 50 different line items. We will break it down, into stone under drives, stone under bridge approach slab, mainline stone, etc. because the cost of the line items is radically different. If our quantity sum is radically different from the engineers' we need to know why. The average price we bid is a conglomerate of the cost of the line items. If we don't know why his item is different from ours, we can get into some major problems. (Contractors United)

Other state have more pay items, and less absorb items. Mass diagrams would be useful. (Reith Riley)

On Ohio and Michigan plans, for each page the quantities are listed. As we go through the plans, we check our take off against that listed quantity, and then we know if there is an error. This is a very good way of the state telling us what

they want. They indicate what sheet and station is indicated and the summaries. If there is a substantial error we are going to play all kinds of games. We would like to be able to confirm the error so we can call the state. In Indiana, the district has them but they won't give them to us. (Reith Riley)

**Graphics:**

## Barrier Wall Pay Units

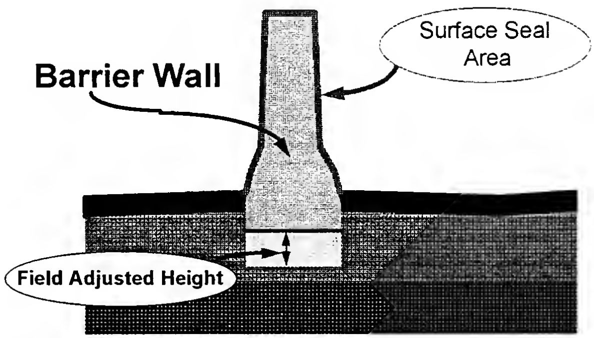
**Guideline:** Specify pay item for barrier walls by the foot.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** So that masonry coat and surface seal will be appropriately adjusted if depth of wall is changed in the field.

**Reasons:** If walls are bid by the cubic yard, a wall height adjustment below grade which is not sealed, will result in a deletion of some pay for surface seal which still must be performed. (Contractors United)
See Barrier Wall Graphic Below.




**If Barrier Walls are priced by the Cubic Yard, field height adjustments will result in too much, or too little paid for surface seal. The solution is to unit price barrier walls by the Linear Foot.**

**Examples:** Calculations of cost impact of using Cubic Yard method.

**Graphics:**

# Bid Packaging

## Package Bids Under $30 Million

**Guideline:** Principles of consistency, spreading the work around, economies of scale, most economical work order size, not combining projects which will be performed by separate contractors anyway (Eg. roads and bridges) should all be considered in the derivation of an INDOT policy to properly administer bid packaging.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Over time, this will result in lower net cost to the taxpayer, and higher quality of constructed product. This is a natural consequence of a healthy competitive and well-distributed market of contractor services.

**Reasons:** Small business has long been touted in this country as being best able to provide the highest quality product for the lowest price. Indeed we spend a great deal of time and money every year to foster small business and break up, or restrict large ones to avoid the very negative social costs associated with market control.

**Examples:** Bid packaging jobs at 40 or $50 million, and combining road and bridge plans limits the number of bidders that can be effective players to those contractors owned by major material suppliers. This results in bids from a few large instate players and some out-of-state contractors. It is arbitrary and restrictive and hurts the industry by not encouraging the smaller contractors to compete with the big contractors. (Leon Beaty)
When done in combination with inadequately prequalifying a job, the result is especially discouraging and even stifling to smaller contractors (the good guys).

**Graphics:**

## Setting Bid Periods

**Guideline:** Provide 4 weeks for contractors to bid major dirt jobs ( > 500,000 CY). Most addendums require a week for the contractor to accomodate. Addendums requiring contractor arrangements for off site borrow or fill require 2 weeks.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Reduced contractor uncertainty at the time of the bid with its associated reduction in contingency.

**Reasons:** Major dirt jobs > 500,000 CY. need 4 weeks to bid. Addendums which include major scope changes, need more than a few days to accommodate. Most addendums require a week for the contractor to accommodate. (Reith Riley)

**Examples:** For example, from the statement that all borrow is available on jobsite, to one requiring the contractor to make arrangements for borrow off site, is a very time-consuming change. Often contractors will spend considerable time at engineers and INDOT offices to obtain advance notice of upcoming jobs to enable economical offsite borrow, waste and other right of way arrangements to be made.

**Graphics:**

## Supplier Certification and Testing

**Guideline:** Put the responsibility for testing and certification on the supplier, rather than having the state do all the testing. Have the state randomly test the material in place. (Leon Beaty)

Qualifiers: 1.

Exceptions: 1.

**Benefits:** This procedure would lower overhead expense for state testing, broaden scope of eligible bidders and increase quality control and competitive bidding.

**Reasons:** This opens the supply areas to include out of state manufacturing companies where the state won't go to test. The current policy is so restrictive that many items such as highway safety devices are effectively sole sourced, and the state pays a non competitive premium for such products.

**Examples:** Safety impact barrels

**Graphics:** Graph of Indiana's cost vs. neighboring states.
Picture and datasheet for competitive products used by other states

# Utilities

## Joint Utility Commission

**Guideline:** Establish a Joint Utility Commission to conduct site surveys, subsurface engineering, right of way staking, and scheduling and management of utility relocations on all INDOT projects.

Each major utility in the state will be required to provide to INDOT an experienced design engineer and such staff as required to do the following:

1. Provide direction and coordination with corresponding utility company records for joint site survey crews to accurately locate utility lines and field hardware. State of the art locating equipment should be provided to these crews by INDOT for joint use.
2. Provide an accurate, alternate cost input resource for relocating their respective utilities to INDOT and consulting design engineers. The goal is to achieve a least-total-cost solution.
3. Review and alter design drawings (including their location on cut sections through phased temporary trafficking systems), and specifications to accurately reflect subsurface engineering for the respective utility. Provide both mobilization time and performance time requirements in the special provisions.
4. Provide central coordinated scheduling and management of utility relocations on INDOT projects, before the contract letting, (if most economical), or during, if so designed.
5. Balance utility resources, provide budget projections, and commit utility company resources for specific projects, times and service levels.

Beyond providing the above services for minor utilities throughout the state, INDOT will provide the joint commission the following:

1. Selection and funding for all INDOT and utility supplied employees, and equipment for field engineering and office staff.
2. General management and coordination between the utilities, with recommendations for hiring and firing joint commission utility employees. Set level of service requirements that will result in lowest net cost to the state.
3. Special provision commitments detailing utility plans for prerequisites, mobilization and performance, including liquidated damages for time delays between the utility and the contractor. Line items in the bid for per-working-day delays due to utility caused hold ups as required for specific job tasks or required phases of construction.
4. Utility contract changes providing for delay costs to be deducted from the utility owners return, rather than being passed on to rate payers through rate increase negotiations.
5. Historical unit cost records of various investigation techniques, and alternatives to prebid subsurface engineering to enable a least cost trade off between such investigative research and the contingencies and field costs which result from the lack of such information during design and bidding.
6. Lead staff for site surveys.
7. Right-of-way staking for all INDOT projects before bid letting, and if needed, early enough to enable all economically feasible utility relocations prior to bidding.
8. Centralized INDOT project schedule control. To coordinate design, right-of-way clearing, receipt of all required state and federal permits before early utility relocations, or bidding.
9. Project management and traffic control services as needed for subsurface engineering, right-of-way staking,

early utility relocations, and other prebid site services.

10. Assess, collect, and distribute liquidated damages from contractors and utility companies for lack of performance.

Qualifiers:

Exceptions:

**Benefits:** This process would save 30-45 days on nearly every project bid by INDOT, which involve the need to move utilities to accomplish the construction. This time savings reduces contractor overhead by its cost of from $10,000 to $20,000 per month, increases equipment utilization by 10% per month saved, and enhances competitive bidding as well as labor wage negotiations. A benefit/cost analysis to justify the expense of funding such a commission, should include the reduction in INDOT project management overhead, and the reduced public cost occasioned by the project time reduction of at least 1-2 months per job. The potential saving is several million dollars per year.

**Reasons:** Utilities are routinely missing or incorrectly shown on design drawings. Current policies provide for utility companies to review preliminary design drawings for existence and location of utilities, and relocate them as directed by INDOT engineers. They are not responsible, however, for the accuracy of their reviews, nor for time delays associated with utility relocation. Neither is there any centralized scheduling effort that recognizes budgetary and resource limitations of the utilities.

The result is; visual site surveys, with underground utility existence and locations based largely upon assumptions; largely inaccurate and incomplete utility information given to designers, who without the slightest confidence in the accuracy of the information, see little value in including utilities when making serious value engineering decisions. Lacking responsibility for errors and omissions, utility reviews of preliminary drawings are routinely performed by utility personal without the education or experience to read and understand them. Comments, if any are received at all, constitute general rules of thumb.

Lacking any responsibility for impacts of their performance delay on the overall cost of construction, as well as their justifiable lack of confidence in the state's time table for letting particular projects; project information and scheduling transmitted to the utility by INDOT, are not passed between utilities central offices and its field offices charged with the responsibility for planning, procurement and scheduling the work. The standard mode of operation is for the successful contractor to contact the utilities shown on the plan, (often the first notice the responsible office has received), soon after the bid letting.

Efficient, mass excavation and demolition equipment cannot be used, indeed construction usually cannot begin until the utility company finally, actually locates their lines. Field redesign of phasing, temporary runarounds & traffic control, and the utility relocation plan is routine. Often a redesign of the final structure takes place, but many options that could have provided very large cost savings, if considered before bidding, are now not expedient. Following this harried and often ill conceived redesign, the utility will order the material, and begin a scheduling process that is necessarily constrained by budgetary and other company commitments and resource limitations.

While this may appear to some as a classical description of general contracting; it is not unlike a construction manager designing hundreds of major rehabilitation projects, without investigative research into existing electrical or mechanical systems, hard dollar bidding each half baked set of plans, and then assigning prime design/build electrical and mechanical subcontractors to the project team; who, have just been given a set of plans, have no responsibility to anyone; but, who are assured of getting paid (directly from the state, or by raising their customer rates) if and when they ever get their job done.

While this description is admittedly simplistic, it is sufficiently accurate to call attention to this complex problem; the result of which is a time constraint, after a notice to proceed, of 1 to 4 months, on perhaps a majority of contracts INDOT bids. This increases contractor overhead by its cost of from $10,000 to $20,000 per month, decreases equipment utilization by 10% per month lost, and restricts or discourages competitive bidding, as well as creating serious impacts on labor wage negotiations. While a notice in the special provisions that INDOT has organized things in this fashion, and that a particular utility will require so many days to perform a relocation function helps; it, in reality, does nothing to establish the length of time the utility will require to mobilize once notice is given, nor does it do more than hint at how long they will take, once they arrive with their materials, to do the job.

This proposed solution recognizes the political infeasibility of paying a contractor with penalties charged a utility, which can due to their legal monopoly status, in turn raise rates to the public. Indeed, we propose to eliminate or

drastically reduce the problem by bringing the utility in as an active part of the investigative research, design, and scheduling team, controlled by the financially responsible party, INDOT.

**Examples:**

The power company on a recent INDOT project had been given verbal permission before the bid to relocate their lines. But, the approved location did not appear on the bid documents. And when discovered by the contractor, it conflicted with the required temporary traffic facilities, effectively closing off dozer and crane access to the project, as well as seriously confining the remaining working envelope due to the need to avoid the crane boom coming closer than 10-15 ft from high voltage wires. (Sweet 1993)

Often, the centerline of the temporary road is given, but not the outside limits. It is essential to draw the whole temporary road where it is going to be; the shoulders, toe, etc., to see how it infringes on other temporary structures and permanent construction processes. The locations of these 3 utility poles were not shown on the plans. It wasn't until the utility company was out on the job setting the poles, that the contractor discovered the problem. (Sweet 1993)

This happens frequently with utilities. Poles are not where shown. Cranes with crawlers are typically 12.5 ft wide. The 'approved' location allowed only 10 ft for temporary passage. Further, they didn't leave enough room to get under the power lines with the crane. The result of these extraneous utility plans changed the whole modus operandi of the job. The contractor was not brought into the picture with the utilities until they were already on the jobsite setting poles. The design for temporary access must consider not just the location of the poles, but also a 4-8 ft cross arm and wires on the poles which may be only 20' high when 80 ft of clearance may be required for the crane boom. (Sweet 1993)

Q: To avoid a high voltage power jump, is 10 feet really a safe distance from a powerline?
A: It is safer for the crane operator sitting in the cab because he is insulated from the ground, than it is for someone grounded, standing on the ground grabbing a concrete bucket or lifted load. We like to keep at least 15-20 feet if we can. (Sweet 1993)

Due to utility design and environmental restrictions, heavy construction equipment owned by contractors and rental companies are currently utilized an average of 6 out of an 8 to 9 month season. Amortization costs must be reflected for this potential utilization in the establishment of unit prices to bid. Union labor rates are also negotiated based on 6 month utilization period as a result of these restrictive provisions. This and indiscriminately applied environmental contract provision effectively cost the state 20 to 30% more in labor and equipment. Finally, the lack of attention to utility design does result in contract cost increases. The state tax payer, contractor or utility user is going to pay more, for a lack of attention during design, to the impact of utilities; costs which can and should be avoided. (Sweet 1993)

We were told verbally and in writing that there was a gas line on a job, but that it was completely out of the way and would not cause any conflict. The first hour on the job, our cat operator fell into a hole and ruptured an 8-inch gas line. A man could have been killed and it cost our insurance company $10,000 to avoid a court battle. So, we now take the attitude that we want the utilities moved completely out of our road. See **Cat hitting 'non existent' 8 inch gas line. Cost $10,000. and nearly the operator's life.**

Utilities are one of the biggest holdups to getting into production. Need more time spent locating underground utilities and making sure they are located on the plans? We have hit 12 inch water lines and on other jobs had to redesign drainage systems on a day to day basis due to things not being as designed. Overhead utilities should be removed before the bid. And if not, then clearly state that they will not be moved. Time frames are given in the bid documents, but no start or ending dates are given. (Leon Beaty)

Drainage pipe elevations should be checked for interferences with roadway subgrade elevations. A six week delay in a project occurred because a pipe was hit while grading the subgrade. This caused a redesign to be made. (Walsh Construction)

Special provision requirement of clearing before utility work is causing double mobilization for contractor and costing the state a lot of money. State is requiring the following:

Mobilize
Clear site
Utility work

Re-mobilize
Start work

This doubles and triples the cost for this part of the project. A least cost solution is to require the utility to clear and do its own traffic control. (Primco Construction)

During the design stage, the designer should contact the power company and study the impact on construction operations. **Overhead power lines affect the feasibility and productivity of crane operations**. For example, when setting a temporary wall, demolition, or driving piling. The power company had to ground the lines and shut some down. **(See video clip 2:20 - Overhead power lines.)** (Weddle Bros. Construction)

**Overhead Power lines in the area can change a 2-day job into a week job**. Even after killing the lower 4 lines. (Leon Beaty)

Graphics:

Pictures of differences between field location of utilities and their location on documents, with resulting impact on operations.
Crane with crawlers and tape at 12.5 feet.
Crane with boom confined by high voltage wires and power pole arms.
Video clip of power jumping 10 feet to a grounded crane boom.
Graphs showing utilization impact on labor and equipment cost

Notes:

King, Russell L., Designing plans for constructability, Preparing for Construction in the 21st Century Constr. Congress, 1991, ASCE, New York, NY, USA. p 744-749.

The writer has obtained several years experience acting as construction engineer for roadway rehabilitation projects as a consulting engineer. In this capacity, it is necessary to provide field engineering services using plans prepared either in-house or by others. Over the years, on numerous projects, in various locations, for a variety of clients, the writer has noticed that not enough consideration was given to existing utilities, right of way constraints, and drainage patterns during project design. Since they were not properly considered, construction and peripheral costs were higher than anticipated construction time was increased, and field changes were made which modified the design concept.

A. EXISTING UTILITIES

The most common utilities are electric, gas, telephone, cable television, sanitary sewer, storm sewer, and water. Most utilities have a permit from a governmental agency for construction and maintenance of their system within the public right-of-way. For this reason, it has become the practice for many designers to assume potential conflicts will be eliminated by having the utility agency relocate their structures. In many cases, this assumption is made with little or no assurance of compliance by the utility owner.

If the design assumes relocation, and if this is not accomplished prior to construction, the complexity of construction increases. It is also more likely that the time for construction increases or that it will be delayed while the conflicting utility is relocated. No matter how much time is given to the utility agency, it is my experience that relocation generally will not begin until construction of the project has begun. Therefore, construction costs will increase because the utility contractor and the project contractor will be working in the same vicinity during the same time period, necessitating more coordination by the project contractor. The cost of providing the coordination is going to be passed to the contract, either as part of the bidding process or through extra cost items.

In many situations, there are solutions to potential utility conflicts other than relocation. As an example, the following field modification was made on two different roadway rehabilitation and widening projects to solve a conflict with an existing telephone duct:

From approximately 3.5 feet to 4.8 feet from the existing E.O.P., a 12-duct telephone conduit was shown on the plans to be in conflict with proposed catch basins, (in this application, a catch basin has a 33 inch sump0. As designed, several thousand feet of telephone duct had to be relocated to install the catch basins every 150 to 200 feet.

In order to eliminate the conflict without relocating the conduit, a field change was made to install inlets, with no

sumps, over the duct, and connect them to the repositioned catch basins.

The additional cost of the inlets was borne by the telephone company. It was estimated that relocating the line would have cost in excess of $75,000 while the inlets, for the same section, cost approximately $10,000.

In order to eliminate conflicts with existing utilities, the location, both horizontal and vertical, must be known. It is my experience that utility atlases are not accurate enough for final design; test holes must be dug. Additional cost to the design of the project may be incurred, but this cost will be significantly less than additional construction costs which may be necessary to construct the improvement as designed without this information. Cost savings to the utility agency are also important, and may be realized if it is not assumed that the utility will be relocated to alleviate the conflict.

It is important to remember the following when designing a roadway rehabilitation if potential conflicts exist between the proposed improvement and existing utilities:

1) All utility structures, both existing and proposed, have a size and shape. They are not just a line on the plans or the symbols used to represent the structure. Obtain the size, shape, and location of existing structures, either through as-built plans or test holes.

2) If a proposed system is to be placed parallel with and deeper than an existing system, leave enough distance between them so an undisturbed bank of earth remains. If the existing system has to be supported, special construction practices must be followed, which always cost more than standard construction practices.

3) Think about and identify what to do with all existing utility structures if they are in conflict. It is easier to make these decisions in the comfort of the office, with all supporting information nearby, than it is in the field with little or no information and a client and contractor concerned about delays and additional costs. In addition, the cost probably will be less and the constructed product may meet the project requirements better. Don't forget, the designer can ignore problems in the office, but they can't be ignored in the field.

4) Work with the utility company. If money saving options are offered to them, they will be more receptive to helping alleviate potential conflicts. Simply expecting them to relocate will close avenues of communication and may force field personnel to reach undesirable conclusions about what alternatives are available when under the pressures of construction.

# Personnel

## Design Engineer & Partnering

**Guideline:** The design engineer should be a part of the project all the way through to completion, and the partnering concept should be continued.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Better project management and coordination and constructability knowledge development.

**Reasons:** No one else in going to know the detail like the engineer, the reasons why, or appropriate alternatives. The need exists to have easy access to the design engineer. (Contractors United)

**Examples:** Get some.

**Graphics:**

## Construction Process Training

**Guideline:** Provide a multimedia training system covering typical construction processes for new designers, inspection engineers and project managers.

Qualifiers: 1.
Exceptions: 1.

**Benefits:** Savings up to 4 to 5% of the total cost of the project can be achieved through effective training and a pay scale that will enable INDOT to retain experienced and qualified people. This is the effect that the inexperience of INDOT people has on the contractor organizations.

We send engineers out of our civil engineering and structural departments with very little construction understanding. They can design, but they don't understand how, what they have designed actually gets built, what equipment is available and how things are really done. We teach optimization by minimizing materials, but do not teach how labor and equipment cost can also be influenced by design decisions. Furthermore, new inspectors don't realize how many dollars are just sitting there idle waiting for them to make a decision or their long term influence on the industry. They need to be educated that the timeliness of their work has a big impact on the cost to do business. When a contractor develops historical unit costs, INDOT's efficiency gets bid in, as higher or lower unit costs.

**Reasons:** INDOT's practice of hiring young engineers right out of school and making them project supervisors and project inspectors, cost contractors a lot of money. Contractors' superintendents, and project managers spend a lot of time educating these people in actual construction practices, and in what is really acceptable and what is not; time to help them read the spec. book and understand it, to gain a feel for construction work. Often they have their specification book, but lack the hands on experience staking, or the confidence to separate what is important from what is not.

And when they get very good at it, they move on to working for contractors, consultants and other businesses. So, the state hasn't done a very good job of training people and keeping trained people out in the inspection field. It is very rare to go out on a project and find experienced, qualified people inspecting the work.

**Examples:** 'Sometimes you have a job that doesn't go very well and one thing that you blame it on is that you couldn't get anything done, because you were trying to work with and train these inspectors. I would be kidding someone to say that people deliberately build that into their bids. It gets built in over a long period of time because of efficiencies and inefficiencies. But, I would venture to say it could be up to 4 to 5% of the total cost of the project. If everything had clicked and INDOT people had really understood what was going on and how to do things.' (Gross 1993)
For example, if we're proof rolling with a roller, loaded truck, operator and a superintendent, inexperienced people inspecting on the job can impact us at $100./hr.

If INDOT had a constructability program available, they could train the inspectors, designers and project managers on an as needed basis, tailored to individual needs, at 50 to 300% faster and cheaper than conventional training methods. Contractors have often shown their willingness to coordinate with us, and let us on their jobsites, to take pictures and ask questions, so that we can record these processes.

Allow for tolerances--include ACI tolerance training module. (Reith Riley)

**Graphics:**
Actual videos of construction processes, displaying both inefficient and non interruptive inspection techniques.

Lots of standard construction systems for slipform pavers and processes are available on Reith Riley's video tape.

## Project Engineer's Work Load

**Guideline:** Do not overload the responsibilities of project engineers.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Increased contractor productivity and higher quality control and project coordination.

**Reasons:** 3 Projects is too many for one engineer.
(Reith Riley)

**Examples:**

**Graphics:**

## Contractor Provided Quality Assurance

**Guideline:** If QA concrete is to be provided by the contractor, have them provide all testing for Quality Assurance.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Lowers net cost of Quality Control.

**Reasons:** If the project requires the contractor to provide the quality assurance on one item, they will be required to have certified technicians on the job anyway. The technician will be certified to run all the tests, so why not let them provide all the tests. (Air, cement ratios, sieve analysis, etc.) (Reith Riley)

**Examples:**

**Graphics:**

## Pay Scale of INDOT Field Personnel

**Guideline:** INDOT needs to research current market labor costs and increase the Pay Scale of their field personnel to match current rates.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Reduction of net construction cost of up to a 4 to 5% of the total cost of the project can be achieved through effective training and a pay scale which will enable INDOT to retain experienced and qualified people.

**Reasons:** This is the effect that the inexperience of INDOT people has on the contractor organizations. When a contractor develops historical unit costs, INDOT's efficiency gets bid in, as higher or lower unit costs.

INDOT has a very sever need to recruit and retain knowledgeable and experienced field personnel. It is very difficult for a contractor to motivate a project engineer to help them with a problem when they are being paid so poorly relative to the contractor's personnel, and haven't had a raise in 5 years.

**Examples:** An equipment operator earns $18 per hour and sometimes puts in 50 to 60 hours a week pulling down $1400-1500. per week. The project engineer has a college degree and is paid far less. It is no wonder they cannot retain good people. INDOT needs to wake up to the 20th century and pay their people. (Reith Riley)

**Graphics:** Show graph of INDOT pay scale vs. Construction industry as well as neighboring states DOT organizations.

# Right of Way

## Clear Legal Access

**Guideline:** Clear legal access to the right of way before the bid.

Qualifiers: 1. None

Exceptions: 1. If this is not possible then we would at least like to know about any right-of-way problems in the special provisions. For example, 'You can't enter partial 41 until Dec. 1st. Then we can handle it. The ones we don't know about, can really throw chaos into a project.

**Benefits:** Reduced time and cost for construction of any impacted transportation facility.

**Reasons:** The designer establishes the right-of-way requirements, and then the right-of-way department purchases the property. When unknown right-of-way clearance problems exist, it creates adversarial relations right off between the property owners, the project manager, area engineer, & the contractor, because we're holding him up. A large change order is the natural outcome, and still it will seldom cover the cost impact on the contractor.

**Examples:** We had 2 or 3 parcels along 38 that because side agreements between county, city and state, we couldn't get right-of-way. This created adversarial relations right off between everyone because we were holding up the contractor. When they are all fighting from the beginning, it really causes trouble. In this case, the state, city and county all expected someone else to purchase the property, no body did.

Sometimes you can get right of entry, and sometimes you can't. We had one parcel in Lafayette where we let the job in May; the contractor started in June; and in December, we finally got right of entry on that property. It held up the water line, sewer line, Indiana gas and general telephone. It was a major part of that job, which is now behind schedule, because **that parcel is right in the middle.**

**Graphics:** Picture of reconstructed area with unavailable parcel superscribed in red.

Also See Constructability Concepts
**Provide 5 Ft ROW From Construction Limits**
**Detail Phased Cross sections**

## Rail Road Approval Before Bid

**Guideline:** Designer needs to get any required railroad approvals prior to the bid instead of contractor.

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Avoids cost additions due to railroad changes and/or time delays resulting from railroad approval processing time.

**Reasons:** Railroad requires approval of anything constructed on their ROW. For example, new bridge beams. This process is time consuming and should be accomplished as part of the design.

**Examples:**

**Graphics:**

## Provide 5 Ft ROW From Construction Limits

**Guideline:** Provide a 5-ft minimum right of way beyond construction limits.

Qualifiers:
1. On all areas with slopes (+ or -)
2. Or high intensity construction such as bridges and temporary roads

Exceptions:
1. Where no slope, grading or construction passage is required at or beyond the construction limit
2. Right of way constriction problems generally only occur in urban areas. (Shutt 1993)

**Benefits:** Reduced cost for construction of bridges and temporary facilities.

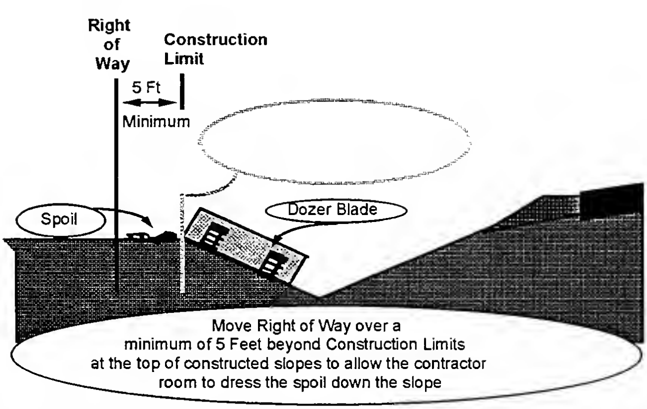
**Reasons:** INDOT contractors have suggested that the construction limits are often designed too close to the right-of-way limits, especially in intense construction areas. This, when it occurs, requires them to do work which cannot be performed without encroachment (going beyond the right-of-way).

The state, by virtue of its right of eminent domain, can purchase land or right of ways at defendable market prices. The current practice of designing construction to be performed at less than 5 feet (usually 0 to 5 feet from the right of way), often requires the contractor to make some sort of deal with adjacent property owners. (See plan graphic.) A contractor will pay anything up to the marginal cost of alternative means of constricted construction, in order to obtain increased temporary limits. This marginal cost may far exceed the market value of temporary use of the additional property. Further, temporary access arrangements can take months or in the worst case be impossible to obtain. Requiring the contractor to make them during the bid can create an expensive level of uncertainty, and can be very disruptive to project scheduling.

When utilities are to be relocated to the area between the right of way and the construction limits, there should be at least 10 feet between them, or the contractor or utility company will have to make a deal with the property owner.

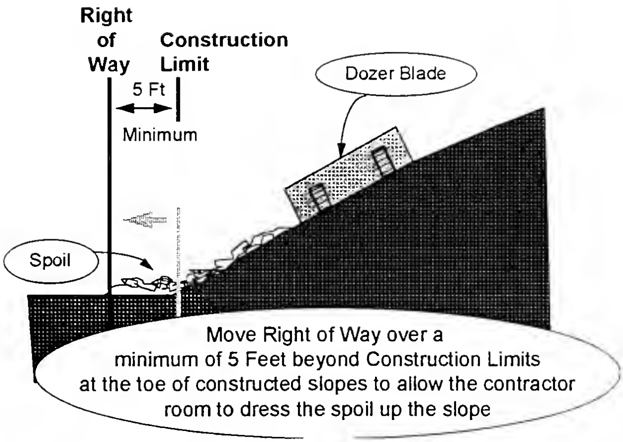
Examples:

If one is cutting a slope or a ditch, the job cannot be done if the construction limits are identical to the right of way limits.




This condition requires either one track on top at the start, or the spoil will come up and require gradually working it back.

The same thing will happen on a fill. The material can be laid in, but it is still going to spill down the slope. And at the end of the job, one must dress it by pushing it back up. A Right of Way at the toe of the slope, does not allow any room to work.




The Right of Way should be shown on the cross sections with both the temporary road and the new facilities. Then one can see if a problem exists. Refer to drawing bottom of previous page. (Listen to audio description by double clicking the microphone icon.)

**Graphics:** Video clips of slope grading
Quantification tables for relative cost of constricted operations to enable cost/benefit tradeoff analysis to justify purchasing larger Right of Way limits.

Further understanding can be obtained by review of the following documents.

King, Russell L., Designing plans for constructability, Preparing for Construction in the 21st Century Constr. Congress, 1991, ASCE, New York, NY, USA. p 744-749.

RIGHT OF WAY RESTRICTIONS Most roadway rehabilitation projects have limited ROW. When it is not politically or economically feasible to obtain additional ROW, the project must be designed to insure adequate area for construction equipment, as well as proposed construction items. Again, if the plans do not consider encroachment or other conflicts with existing ROW limits, field challenges will be made to alleviate them and the changes *may* not be in the best interest of the project.

The problems with ROW constraints are often more subtle than with utilities. There is no doubt when an existing utility line is hit, but there are many variables for ROW constraints. An existing fence on private property may restrict the swing of a backhoe or in other ways limit the maneuverability of excavating equipment. An existing tree on private property, but near the ROW, has roots that can conflict with proposed excavation.

An example of ROW constraints not properly considered:

A proposed storm sewer system was designed to be at 30 feet to center line in a 33-foot ROW. Usually, there was a thick buffer of trees along the ROW and, often, there were fences at the ROW line. To excavate the trench, the contractor had to operate his equipment at an angle to the trench, thus slowing operations. This tight working condition was reflected in his bid. To reduce conflicts as much as possible, the system was moved away from the ROW as far as possible.

Another project also experienced tight working conditions, described as follows:

A retaining wall was designed with the toe of the foundation at 29.5 feet in a 30-foot ROW, with no easement for excavation or equipment. Fortunately, a field decision was made to eliminate the wall, so a solution for constructing it was not required. It is probable that encroachment would have been the only solution without waiting until an easement could be obtained.

As with other conflicts, ROW constraints must be eliminated in the design of the project so they do not have to be

eliminated during construction.

People who have performed construction engineering services know there are always problems during construction that cannot be anticipated during design. Adverse weather conditions, strikes, equipment breakdowns, and contract document interpretation are a few examples. Inspection of work and materials, authorizing payment for completed work, preparing change orders, dealing with unhappy residents and the motoring public, and other work normally associated with a construction project; are enough to keep field personnel busy. All decisions that can be made in the office about alleviating potential conflicts will simplify construction and field engineering. In addition, significant cost savings can be experienced if proper engineering design is performed. In closing, I would like to reiterate that problems with potential conflicts can be ignored during design but they will have to be solved during construction.

Also, See Constructability Concepts
**Clear Legal Access**
**Detail Phased Cross sections**

# Environmental

## Site Clearing for Indiana Bat

**Guideline:** Investigate the applicability of DNR time restrictions on Site Clearing for each project and apply for permits prior to the bid.

Qualifiers:

1. Is the project simply a realignment, with all ground clearing within 100 feet of an existing road? If so, the provision doesn't apply.
2. Lack of planning and coordination with utilities prior to the bid, may also limit contractor use of this prime construction period.
3. Lack of detailed investigation by DNR for protection of fish habitat may also limit use of a portion of this period.

Exceptions:

1. Does a special provision exist from DNR restricting all clearing between May 1 and September 1?
2. Do these dates conflict with the projected start up of the contract?
3. Is this a relocation with all ground clearing within 100 feet of an existing road? If so, the provision doesn't apply.

**Benefits:** Lifting the restriction or narrowing it in time and scope to what is actually needed to protect the Indiana Bat; reduces contractor overhead by its cost of from $10,000 to $20,000 per month, reduces INDOT project management overhead and traveling public cost by the project time reduction of at least 1-2 months per job, increases equipment utilization by 10% per month saved, and enhances competitive bidding as well as labor wage negotiations.

**Reasons:** Many state contracts include the following special provision: "To minimize project-related impacts on the Indiana bat, *Myotis Sodalis*, all clearing shall be performed between September 1 and May 1, when the bat is not expected to be in the project area." The provision was instigated to protect the endangered bat habitat throughout the state during these periods from destruction due to construction clearing. Site clearing is usually the first required activity on the project, is on the critical path and until it can be performed precludes the start up of all other site activities. Bats will not usually come within 100 feet of an existing road. Therefor, after the bid, and at the request of the contractor, this blanket provision is often limited to clearing restrictions beyond this 100-foot zone by DNR. If the provision as written is in force during the bid, however, the contractor is led to believe that a contract bid in May could not begin until September. So, some contractors may decline to bid if they are led to believe that they will not be able to begin construction until after the prime construction season. This reduces contractor interest and thus the competitive performance of the bidding process. The provision's cost impacts may be included and eventually paid by the state even if eventually lifted.

**Examples:** An 8 to 9 month construction season exists in the state of Indiana. The season begins in March or April and ends in October or November. While causing no impact on the bat's habitat, if this and proper planning for utilities were accomplished prior to bidding, it would provide for maximum utilization of available labor and equipment resources

during the full 9 months. The construction of both new bridges, temporary bypass structures and roads usually require some clearing. The logic and inconsistency of the application of this provision seems to baffle contractors. Uncertainty increases contract cost at the time of the bid. After bidding, cost and time savings, if achieved, stay with the contractor. If the state would do the detailed investigation initially, and include only those provisions which specifically apply, the savings would be theirs. As a result of this provision, in channel excavation restrictions, and utility coordination problems, heavy construction equipment, owned by contractors and rental companies in the state of Indiana, are currently utilized an average of 6 out of an 8 to 9 month season. Amortization costs must be reflected for this potential utilization in the establishment of unit prices to bid. Union labor rates are also negotiated based on 6 month utilization period as a result of these restrictive provisions. This and similar indiscriminately applied blanket contract provision effectively cost the state 20 to 30% more in labor and equipment.
**Graphics:**

Pictures of required clearing operations
Graphs showing utilization impact on labor and equipment cost
Pictures of Indiana bat habitat

## Rule 5 Interpretation and Enforcement

**Guideline:** Have erosion control plans designed as part of the bid documents and paid for as a bid item, applied for by the state prior to the letting. If over 5 acres and the permit is required, then have the state apply for the permit and make it transferable to the contractor. (Reith Riley, Leon Beaty, Switzer & Huckleberry)

Qualifiers: 1.

Exceptions: 1.

**Benefits:** Reduced construction time and uncertainty at the time of the bid.

**Reasons:** Erosion control/Rule 5 is in contracts this year. Lots of time is required for application of this permit. The federal guidelines are not specific to a contractor. Some options exist, but basically the requirements are specified for the type of operation to require type 'A' or type 'B' erosion control. It could be done prior to the letting. Further, it could be a difficult problem to really enforce keeping all the sediment from a bridge construction project on site, not letting it get into the stream. Just what is to be done and how is a design function. (Switzer & Huckleberry 1983)

Note: An expert system appears very appropriate for representation of the design process required for this new executive order.

**Examples:**

**Graphics:**

## Wetland Identified Before Bid

**Guideline:** Wetland-- what is a wet land requires a biologist to come out and check. If a contractor is in a floodway or flood plain and wants to get any borrow or do any spill, he has to get that checked out. We want to have all this done prior to the bid. (Switzer & Huckleberry 1983)

????? Must identify additional qualifiers to correlate with contractors desire to make their own arrangements to purchase properties for cut and fill.

Qualifiers: 1.

Exceptions: 1.

**Benefits:**

**Reasons:**

**Examples:**

**Graphics:**

## IDEM Permits Before Bid

**Guideline: IDEM permits** -- The Indiana Dept. of Environmental management requires a permit for any demolition, technically. We would like them to handle that prior to the letting. (Switzer & Huckleberry 1983)

Qualifiers: 1.

Exceptions: 1.

**Benefits:**

**Reasons:**

**Examples:**

**Graphics:**

## Gas Tank Removal Procedure

**Guideline:** Provide Contractors and the district project managers with an itemized, step by step procedure of what they are to do when they run into gas tanks and/or contaminated soil. It should identify who is involved, and who to contact if they hit one of these things when it is not shown on the plans.

Qualifiers: 1.

Exceptions: 1.

**Reasons:** This is becoming a more frequent and unexpected event. This is all in-house, but it still has a lot of conflict between departments. (Switzer & Huckleberry 1983) What to do has been investigated and outlined by many sources. Reduction of contractor and INDOT uncertainty with a clearly defined if-then rule base with examples and phone numbers is clearly achievable.

**Examples:** A project with impacts due to undefined procedure.

**Graphics:** Pictures, safety examples and environmental hazards

## State Specific In-Channel Restrictions

**Guideline:** Investigate the applicability of Department of Natural Resource (DNR) time restrictions for In-Channel excavation on each project prior to the bid.

Qualifiers:

1. Does a special provision exist from DNR restricting in channel excavation between April 1 and July 1st on the project?
2. Do these dates conflict with any of the projected time of the contract?

Exceptions:

1. Are fish actually spawning in the contract area during the restricted times?
2. Lack of planning and coordination with utilities prior to the bid, may also limit contractor use of this prime construction period.
3. Lack of detailed investigation by DNR for protection of Brown Bat habitat may also limit use of this period.

**Benefits:** Lifting the restriction or narrowing it to what is actually needed to protect the state fish; reduces contractor overhead by its cost of from $10,000 to $20,000 per month, reduces INDOT project management overhead and traveling public cost by the project time reduction of at least 1-2 months per job, increases equipment utilization by 10% per month saved, and enhances competitive bidding as well as labor wage negotiations.

**Reasons:** Many state contracts include the following special provision: "To minimize project-related impacts upon fish spawning, no in channel excavation shall take place between April 1 and June 30." The provision was instigated to protect fish migrating or spawning throughout the state during these periods from construction induced silting. At the request of the contractor, this blanket provision is often reduced or eliminated after the bid (pending a detailed site investigation of temperature, species, and other factors by DNR). If in force during the bid, the provision's cost impacts are included and eventually paid by the state even if eventually lifted.

**Examples:** An 8 to 9 month construction season exists in the state of Indiana. The season begins in March or April and could proceed, making use of available labor and equipment resources during the full 9 months, if this and proper planning for utilities were accomplished prior to bidding. The construction of both new bridges and temporary bypass structures require in channel construction. DNR's broad generalization has been applied during bidding to dry stream beds and small ditches carrying apparently uninhabitable runoff, regardless of size. A wavier, if applied for after the bid, results in a site visit by DNR, and frequently an allowance for certain types of in channel work to be done for specific time frames and activities. Cost and time savings, if achieved, stay with the contractor. If the state would do the detailed investigation initially, and include only those provisions which specifically apply, the savings would be theirs.

Heavy construction equipment owned by contractors and rental companies are currently utilized an average of 6 out of an 8 to 9 month season. Amortization costs must be reflected for this potential utilization in the establishment of unit prices to bid. Union labor rates are also negotiated based on 6 month utilization period as a result of these restrictive provisions. This and similar indiscriminately applied blanket contract provisions effectively cost the state 20 to 30% more in labor and equipment. Finally, some contractors may decline to bid if they are led to believe that they will not be able to begin construction for 2 to 3 months after contract letting. This reduces contractor interest and thus the competitive performance of the bidding process.

Note: There was a small job restricted to 3 women or minority owned businesses bid in November. But due to the listed environmental restrictions, I could not go to work until June. It is important to note that, $848,000 would have sat on my prequalification for 7 months, if I got the job. I am a small contractor, that would have consumed my capacity to bid during that time. So, **I put enough money in it that if I got the job, it was worth my while to sit around until I**

**could go to work.** (Shutt 1993)

Note: There needs to be some actual determinations of whether they are going to wave it or not. A typical example would be Highway 26 west of Lafayette. The contract stated both restrictions, eliminating clearing from May 1 to Oct. 1st and all in channel excavation from April 1 to June 30th. The project was let in March, with a notice to proceed in April. **These restrictions basically eliminated this year's work.** Both were pulled after the bid. Instead of the bridge, which they had assumed, it turned out to be a pipe.

Note: If from the litigation report, it says no in channel construction. Then can I build a causeway out there and put rip rap in the creek? I don't think that was DNR's intent. It is a silting problem. The clause varies from 'no work in stream, to no in channel excavation, to no in channel construction work. **We don't know what to enforce or even what is meant by these statements.** (Switzer & Huckleberry 1983)
Graphics:

Pictures of required in channel operations
Graphs showing utilization impact on labor and equipment cost

| Heading | Sub-Heading | Lesson Learned | Icons | Back | Potential Savings/Job Minimum | Maximum |
|---|---|---|---|---|---|---|
| Bridges | | | Bridge | Bridges | | |
| | | Avoid Camber Ponds | Ponds | Pond | $20,000.0 | $100,000.0 |
| | Foundations | | Found | Foundbck | | |
| | | Use of Cofferdam Bottom Seal | Cofdam | CoffSeal | $10,000.0 | $30,000.0 |
| | | Deep Foundations Alternatives | depfound | Foundalt | $50,000.0 | $100,000.0 |
| | | Accurate Pile Lengths | Piles | | $1,000.0 | $5,000.0 |
| | | Consider Economical Foundation Types | | | $50,000.0 | $100,000.0 |
| | Total Savings | | | | $111,000.0 | $235,000.0 |
| | Concrete Materials | | Con_mat | Con_mat | | |
| | | Concrete Strength | Con_stre | Con_stre | $3,000.0 | $15,000.0 |
| | Steel Bridge Girders | | | | | |
| | | Use of Seismic Isolation Bearings | Bearpad | Bearpad | $20,000.0 | $100,000.0 |
| | | Web Stiffener to Tension Flange Connection | Ten_flng | Ten_flng | | |
| | | Plate Girder Spacing | Pl_g_sp | Pl_g_sp | | |
| | Total Savings | | | | $20,000.0 | $100,000.0 |
| | Concrete Bridge Girders | | | | | |
| | | Use of Modified T-Bulb Girder | | | | |
| | Forming | | form1 | Formbk1 | | |
| | | Bridge Abutment Forming | bdabut | | $5,000.0 | $20,000.0 |
| | | Pier Cap Extensions | Piercap | Pcap | $5,000.0 | $20,000.0 |
| | | Slope Bottom of Column Capitals | SlopeCap | ColCap | $5,000.0 | $10,000.0 |
| | | Research New Stay-in-Place Forms | Stayform | Stay_Fm | $50,000.0 | $150,000.0 |
| | | Bridge Pier Cap | Pcap | Pier_cap | | |
| | | Standardize Forming Sizes Etc. | Formsize | Std_Form | | |
| | | Bridge Deck Overhang | | | | |
| | Total Savings | | | | $65,000.0 | $200,000.0 |
| | Forming Bridge Pier Columns | | | | | |
| | | Reduce Column Width to Lower Seismic Forces | Col_seis | Col_seis | | |
| | | Standardize Column Diameters | Colform | Std_Col | | |
| | | Architectural Bridge Pier Column | TaporCol | TaporCol | | |
| | Total Savings | | | | $0.0 | $0.0 |
| | Components | | Componen | | | |
| | | End Section Toeplates | Toe | Toeplate | $10.0 | $1,000.0 |
| | | Establish a Uniform Joint Spec | | | $1,000.0 | $5,000.0 |
| | | Hoods on Catchbasins | | | $1,000.0 | $2,000.0 |
| | | Boxed End Sections | | | $100,000.0 | $200,000.0 |
| | Total Savings | | | | $102,010.0 | $208,000.0 |
| | Work Area Design | | WKArea | Work_Area | | |
| | | Increase Work Zone Size | | Work_Zn | $50,000.0 | $300,000.0 |
| | | Detail Phased Cross Sections | Phas_X | PhaseX | $5,000.0 | $150,000.0 |
| | | Complete Run Around Design | | | $5,000.0 | $100,000.0 |
| | Total Savings | | | | $60,000.0 | $550,000.0 |
| | Existing Structures | | Exstruc | | | |
| | | Very Old Existing Structures | | | $5,000.0 | $100,000.0 |
| | Road Interface | | Roadint | | | |
| | | Bridge-Road Transition | | | $20,000.0 | $250,000.0 |
| Total Savings (Bridges) | | | | | $406,010.0 | $1,758,000.0 |
| | | | | | | |
| Roads | | | Road_IC | Road_bk | | |
| | Work Area Design | | WKArea | Work_ara | | |
| | | Increase Work Zone Size | | | | |
| | Components | | Component | | | |
| | | Hoods on Catchbasins | | | | |
| | | New Curbs on Existing Drives | | | $1,000.0 | $5,000.0 |
| | Total Savings | | | | $1,000.0 | $5,000.0 |
| | Drainage | | Drainage | | | |
| | | Properly Size Manholes | | | $0.0 | $10,000.0 |
| | | Boxed End Sections | | | | |
| | | Interior and Exterior Drains | | | | |
| | | Cleanouts on Edge Drains | | | | |
| | Total Savings | | | | $0.0 | $10,000.0 |
| | Earthwork | | Earth | Earth_wk | | |
| | | Define Line of Sight Contours | | | $5,000.0 | $20,000.0 |
| | | Bituminous Coated Underlayments | | | $1,000.0 | $2,000.0 |
| | Total Savings | | | | $6,000.0 | $22,000.0 |
| | Linear Grading | | Grader | | | |
| | | Implement Current Linear Grading Policy | | | | |
| | Concrete Paving | | C-Paver | Con_Pave | | |
| | | Specify Standard Concrete Paving Widths | Width | P_Width | | |
| | | Longitudinal Joint Spacing | LongJnt | | | |
| | | Standardize Forming Sizes Etc | | | | |
| | Total Savings | | | | $0.0 | $0.0 |
| Total Savings (Roads) | | | | | $7,000.0 | $37,000.0 |
| | | | | | | |
| Contracts | | | Cont | Contrac | | |
| | Plans | | Plans | PlansBac | | |
| | | Avoid Overloaded Drawings | | | | |
| | | Reanalyze Achieved Plans | | | | |
| | | Redesign combined plans | | | | |
| | | INDOT Should Check Consultant Designs | | | | |
| | | Field Verify Existing Structures | | | | |
| | | Use Construction Schedules | | | | |
| | | Notes on Drawings | | | | |
| | | Dimensions on Drawings | | | | |
| | | Skewed End Bent Views | | | | |
| | Total Savings | | | | $0.0 | $0.0 |
| | Traffic Maintenance | | Traffic | | | |
| | | Center Lane Closure | | | | |
| | | Traffic Control Plans | | | | |
| | | Night Watchman | | | | |
| | Total Savings | | | | $0.0 | $0.0 |
| | Pay Items | | PayItem | | | |
| | | Scope Reinforced Earth Pay Items | | | | |
| | | Make Shear Studs a Pay Item | | | | |
| | | Pay Item for Top Soil Dressing | | | | |
| | | Reduce Catch-All Items | | | | |
| | | Effect of Pay Item Errors | | | | |
| | | Barrier Wall Pay Units | | | | |
| | Total Savings | | | | $0.0 | $0.0 |
| | Bid Packaging | | Bid | | | |
| | | Package Bids Under $30 Million | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | Setting Bid Periods | | | | |
| | | Supplier Certification and Testing | | | | |
| | Total Savings | | | | $0.0 | $0.0 |
| | Utilities | | Utilities | | | |
| | | Joint Utility Commission | | | | |
| | Personnel | | Person | | | |
| | | Design Engineer & Partnering | | | | |
| | | Construction Process Training | | | | |
| | | Project Engineers Work Load | | | | |
| | | Contractor Provided Quality Assurance | | | | |
| | | Pay Scale of INDOT Field Personnel | | | | |
| | Total Savings | | | | $0.0 | $0.0 |
| | Right of Way | | Row | Row | | |
| | | Clear Legal Access | Legal | | | |
| | | Rail Road Approval Before Bid | RRApprov | | | |
| | | Provide 5 Ft ROW From Construction Limits | Row5 | Row5 | | |
| | Total Savings | | | | $0.0 | $0.0 |
| Total Savings (Contracts) | | | | | $0.0 | $0.0 |
| | | | | | | |
| Environmental | | | Envr | Enviro | | |
| | | Site Clearing for Indiana Bat | | | | |
| | | Rule 5 Interpretation and Enforcement | | | | |
| | | Wetland Identified Before Bid | | | | |
| | | IDEM Permits Before Bid | | | | |
| | | Gas Tank Removal Procedure | | | | |
| | | State Specific In-Channel Restrictions | | | | |
| Total Savings (Environmental) | | | | | $0.0 | $0.0 |
| | | | | Total Savings | $413,010.0 | $1,795,000.0 |

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